OLUME 52 NUMBER 3 . . . . ONE YEAR FOUR DOLLARS

# GENERAL ELECTRIC Review

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March, 1949

**two great names**

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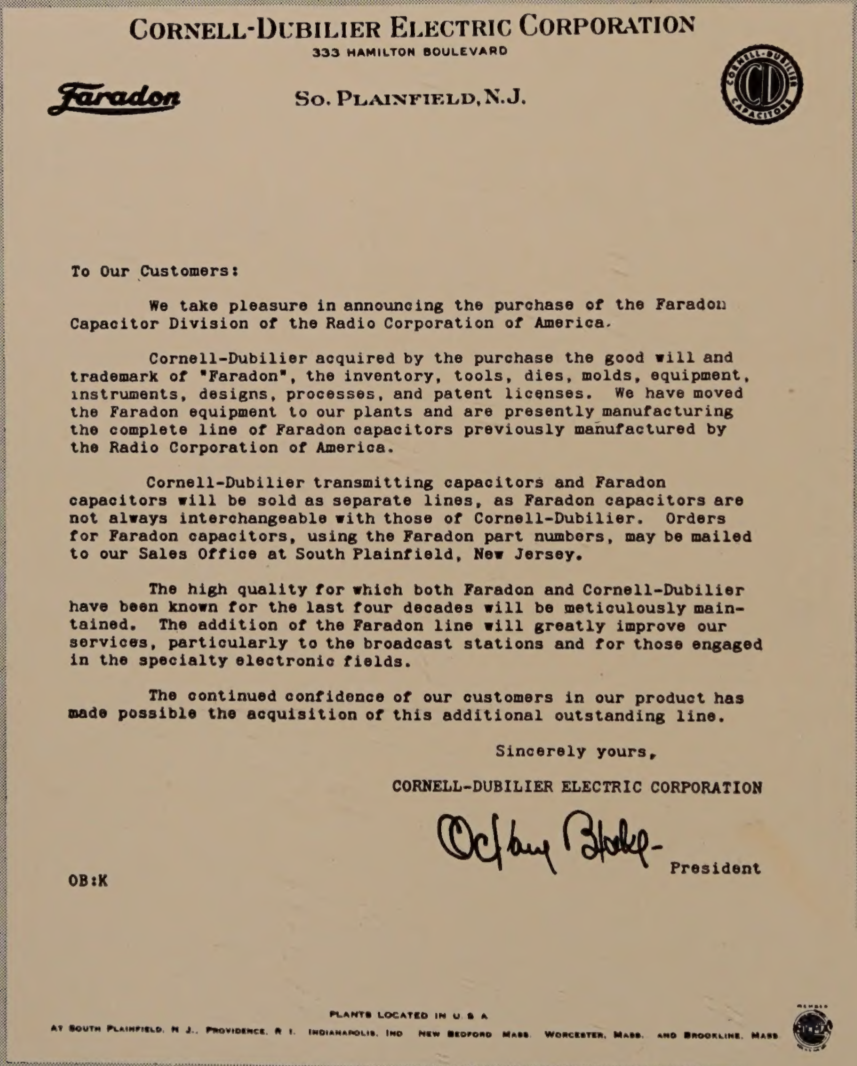
*In The Broadcasting And Specialty Electronics Fields*



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# HE PROFESSIONAL ESTATE*

**The issues confronting this country are plain, the stakes are high, and danger is apparent. The situation demands intelligent expression and action. It is unsafe for scientists and engineers to delegate to others their duties of citizenship. For them to withdraw into cocoons of technology is to assume the spurious mantle of a protected class**

C. E. Wilson

By CHARLES E. WILSON
President, General Electric Company

ALMOST one hundred and twelve years ago a distinguished New England man of letters arose o address the Phi Beta Kappa Society at its annual eeting in Cambridge, Massachusetts. His subject was he same as had been assigned to a speaker on that ccasion year after year, but he made it indelibly his wn; and it has survived the century and more to ecome a familiar piece of required reading in almost very high school and college English class. I am not amiliar with the elements of the literary diet which is orce-fed to budding engineers as a cultural offset to heir grimmer subjects, but I would be a little surprised most of you had not already identified the speaker as alph Waldo Emerson, and his subject as "The merican Scholar."

I would not pretend for a moment that I have reached ack into my own school days, which were all too brief, o recall this famous essay, because I was far too busy ursuing the endless and elementary chores assigned to ne by the Sprague Electric Company to indulge myself n the flowering of New England culture. But I got round to it later—a lot later. The other day when I ad opportunity to examine the advance program of his A.I.E.E. winter meeting and found that I was to ome in somewhere between the conference on electrical ests on dielectrics in the field and another conference n the control of electric hazards in rural areas, it ccurred to me that perhaps I could make the best ontribution to this learned and expert audience by tanding up and reading "The American Scholar." It vill take me a few minutes to explain that conviction, nd what you are about to receive will be the explanaion, and not the essay.

### E THE MASTER NOT THE SERVANT OF YOUR KNOWLEDGE

Engineers quite often assemble in groups to examine heir problems, but only rarely, it seems, do they stand ff as individuals and examine themselves and their elation to society. This is a usual characteristic of pecialists. The scholar was such a specialist in 1837, nd he still is one today, of course, but then he stood lmost alone upon the American scene as the prime xample of the professional man.

I dare say that the Phi Beta Kappa Society, with its roster of ministers, lawyers, doctors, and teachers, pretty obviously represented not only the most concentrated scholarship of its day on this side of the Atlantic—the elite among literate men—but it also stood for something else. It stood for the aggressive and important forces in American life which had then attained the greatest development, and which were most respected and admired. Because this was so, Emerson set himself a task which seemed to him most important. Gently but firmly, with the welfare of the infant United States uppermost in his mind, he sought to lift the nose of the American scholar out of the book in which it was buried and point it into the wind, so that it might sense more truly what was going on in the world. What you have done is good and important, he said in effect, but you must be the master and not the servant of your knowledge. It is not enough to turn forever inward and become nothing but a specialist. You are a part of society as a whole; you have duties and obligations as well as privileges and distinctions.

There is a curious and authentic similarity between the position of the American scholar in 1837 and the position of the engineer and physical scientist in 1949. It is not straining at the truth to say that the American Institute of Electrical Engineers and its companion societies of the engineering and scientific world bear to highly mechanized modern life the same relation which the organized scholars of Emerson's day bore to the more pastoral American scene of which they were a part.

### THE ENGINEER-SCIENTIST TODAY STANDS SQUARELY IN THE CENTER OF THE STAGE

It would be foolish for us now to attempt to evaluate the relative importance of the doctor, the lawyer, the economist, the teacher, and the engineer—to name just a few—in our present scheme of things. That is not necessary to make the point. All of us have our work cut out for us, and it is specialized and important work in a highly specialized world, at a critical stage in the development of civilization. But certainly the one overwhelming characteristic of this modern world is its tremendous material achievement and its vital dependence upon technology and science. Our politics are shaped by our economics, and even our economics are but the swiftly passing reflection of the scientific and

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*An address delivered by Mr. Wilson on Feb. 2, 1949 at the AIEE General inter Meeting in New York City. Its inspiring and instructive message is vital import to all scientists and engineers—ED.

This article is so paged that without mutilating other articles, it can be adily removed for filing as a group of full-size consecutive pages.—EDITOR technological progress of man. We have been caught up, in this century, in a whirlwind of new knowledge and the application of that knowledge, and it has left us breathless and trembling.

You will agree with me that with the dropping of the atomic bomb we were suddenly shocked into a realization, an awesome realization, that our human capacity for intense specialization had got tragically ahead of our human capacity for thoughtful adjustment. For a time we seemed to hang in terrible and chaotic suspense over a yawning abyss of our own making, without knowing just what to do about it. Hiroshima was in a sense the final and rather staggering piece of evidence to prove, if more proof were needed, that the engineer-scientist today stands squarely in the center of the stage. He is that member of the professional estate most responsible for the nature of the world in which we all live. He has achieved distinction in the practice of his specialty, just as the New England scholars did in theirs. And like the scholars, he must solemnly consider his duties and obligations to society. You are part of this professional estate.

### DUTY OF THINKING MEN TO LEAD THE WAY TO A BALANCED AND INTEGRATED SOCIETY

Emerson introduced an ancient fable, that the gods in the beginning had divided *Man* into *men*, in order that he might be more helpful to himself. Emerson was extremely critical of the fact that Man had become so metamorphosed into a thing, and had become so engrossed in his specialization as a farmer or a professor or an engineer, that he had lost sight of the fact that in the beginning he was universal Man, the original fountain of power. "You must take the whole society to find the whole man," he said, so subdivided and distributed has he become, and with increasing specialization this becomes harder and harder to do. His final point was this: that it is the duty of thinking men, and particularly of the scholar, as the foremost professional man of his age, to leave off being a mere bookworm and lead the way back to a balanced and integrated society. If it is true, as I think, that the engineer-scientist is the foremost professional man of this age, then do you here not also have the obligation and the duty, as individuals and as an association, to give some thought to playing a similar role for the age which you have created?

### BE NOT THOUGHT-TIED AND TONGUE-TIED TO SCIENCE AND TECHNOLOGY

This may seem to be a rather abstruse subject, and in marked contrast to those you are considering at this meeting. It is one of those strange quirks of human nature that most men are not at all embarrassed or reluctant to discuss with their fellows the day-to-day technical and professional problems in which they are engaged; but the more their minds run to shop talk on any plane, the more tongue-tied and thought-tied the become when a general question of morals or huma behavior is posed. And yet these are very simpl matters. The American Medical Association, th American Association for the Advancement of Science and the American Institute of Electrical Engineers, fo example, do not and cannot operate in the rare atmosphere of science and technology alone. Once they could perhaps, but not today. Their members are not machine but men. By banding together they have become greate and the sum is more significant than the parts. By you association you have increased your professiona stature and taken upon yourself, perhaps unconsciousl the duty to support and strengthen the society of whic you are a part. You are bound henceforth not only t understand the technological progress which you ar achieving in your specific ways, but you must unde stand the kind of society which supports that progres and is in turn borne forward on its shoulders.

### FULLY MERIT THE HIGH REGARD PAID YOU BY NONPROFESSIONAL MEN

I suspect that you underestimate your influence, a professional men. It is my impression that people i general are more likely to trust and admire an enginee or a scientist than they are a lawyer, or a teacher, or soldier, or certainly a business man. Perhaps th reason is that this attitude towards engineers is symbolic. There is probably a psychological explanatio for it, but by and large you enjoy a wholesome status i the public mind similar to that enjoyed by a policema or a big brother in the mind of a small boy. It stem from your concern with progress, from the fact tha you work with materials and build things, and are a least theoretically untainted by having to deal wit petty human concerns. If this does not jibe with you personal experience, please remember that I am givin you only the very general view from a lot of very sma and uninformed birds. For all that, it should not b discounted.

Another explanation of your high station in the eye of the common man lies in the fact that he does no understand what you are doing. One of my associate in addressing a group of scientists the other day, said "What takes the heart out of the average man when h is confronted with atomic theory is the sneakin suspicion that he never got around to understandin relativity, as of approximately the year 1925, or th quantum theory, of about 1900. We subconsciousl yearn for all the complex machinery that serves us s well in our daily lives, without the complex problem that attend them. We all secretly long for a log cabin o a mountainside—with a two-lane concrete highway to or almost to, our door; with air conditioning and television, and an electric kitchen; but with none of th troubles that attend a society which has those facil ties."

So much for some of the illogical but powerful reasons why you are highly regarded by the nonprofessional class. What are you doing to deserve this regard, not as bridge builders and physical scientists, not as experts on distribution transformer and secondary conductor economics, but as *social* and *moral* scientists and engineers?

### YOU HAVE COME TOO FAR TO DENY NOW YOUR SOCIAL AND MORAL RESPONSIBILITIES

You must find, I am sure, as you consider these questions of your professional stewardship, that it is no longer possible for you just to confine your efforts to electrical engineering. I am reminded here of a statement made in 1922 by Charles A. Coffin, founder of the General Electric Company. He was then in his 78th year, and was speaking to a reporter from the *New York World* in one of the very few interviews he ever granted.

"When we set up our research laboratory," he said, "we couldn't confine the research to commercial purposes. We gathered together the greatest scientists we could find. We equipped them with everything they needed to carry on their experiments. Not that we were better people than others, but because of the peculiar forces with which we were dealing, we soon found that we could not limit such an organization to the aim of making money."

The peculiar forces with which you are dealing today will likewise make it extremely difficult for you to limit yourselves, in this modern world, to those matters ordinarily listed as the proceedings and transactions of the Institute. You have come too far, you and those who preceded you, and you have powerfully affected and shaped the lives and destinies of too many millions of people, to deny your responsibility now. Brick by brick, step by step, computation by computation, you have with your own brains and hands built a great structure and equipped it with the machines and devices which have made American living and working standards the highest in the world. Our economic strength, our productive efficiency of which we are rightly proud, our free competitive markets, our enviable industrial machine, the abundance of our harvests, our leadership in research and technological achievement—in fact, every element of our fabulous enterprise system—bears the proud imprint of the engineering profession. So intensely have you concentrated on your specific tasks that you have probably not been aware of the magnitude of the whole job, or your own intimate connection with it.

Then what are the things that we ordinary citizens expect you to do that you have not done before? What is it that we now feel we have a right to expect from your professional estate? The very same things that Emerson demanded from the American scholar more than a century ago—understanding and action. In your preoccupation with your slide rule you cannot safely leave to others—to the economists and politicians and lobbyists—the larger job of defending the way of life which was made possible by your own contributions. You have no right to delegate the duties of citizenship simply because you have a test to run, or a specification to write. You have no right to turn away from such problems as education, taxation, government reorganization, national security, civil rights, labor and management, or atomic power development, simply because they may involve you in controversy and take your time. It is quite true, of course, that no man today has the right to turn his back upon these things, but the professional man has a particular obligation to society, to understand and to act.

### TO PRESERVE OUR RIGHTS WE MUST SUPPORT THE STABILITY AND SAFETY OF THE COMMUNITY

I have heard of an interesting doctrine in our common law which excellently illustrates the nature of this obligation. The lawyers call it the doctrine of lateral support, and it arises out of this set of circumstances. A man who owns a piece of land free and clear has the right to do with it as he wishes. If he wants to dig a hole or excavation that will extend all the way from his property line on one side to the property line on the other side, he may do so—that is his privilege and his right, and his neighbor cannot lawfully complain. But if, as a result of such an excavation, the land on his neighbor's side of the line begins to crumble and fall away, the man who dug the hole on his own property is liable for the damage. In other words, every landowner has the right to rely upon his neighbor for the support of his own land.

All of us are landowners in the community of our fellow men. What we do on our own piece of ground to maintain our livelihood and pursue happiness is our own business. We can be printers or acrobats or engineers because that is our right as free men, and we cannot complain if our neighbors on either side ply their trade as shoemakers or farmers or automobile salesmen. But we plainly enjoy our rights at the price of an obligation—the obligation to insure the stability and safety of that community through intelligent conduct of our own affairs. That in turn results in our having an additional right—the right to rely upon our neighbor for support and understanding. Thus does the law reflect an even more ancient law, the golden rule of human conduct.

The day is indeed past when the professional man could delegate his understanding and his action, in a sphere not especially his own, to some selected advocate, or else neglect it altogether. For example, political theory and engineering still strike most of us as strange bedfellows, yet it is now apparent that a little critical study of the writings of Karl Marx and the Communist Manifesto would not have been an entirely useless provision in our technical curriculum. When Communism jumps at you out of every headline and from around every familiar corner, the situation of even the average man becomes a little uncomfortable, and that of the professional man may be particularly difficult.

### COMBAT THE COMMUNIST THREAT TO OUR WELFARE

Since it is clear that officially, openly, and aggressively, the Communist party has the intention, and certainly the hope, of destroying the American system as it now exists, we need no longer concern ourselves with doubts on this score. The issues are plain, the stakes are high, and at long last even the degree of our danger seems to be apparent. What vexes and annoys most Americans today is largely the question of *who* are the Communists, not *what* are they. And that is where the discomfort occurs. So ingrained in each of us are the convictions that civil liberties are worth preserving, that an individual is innocent and deserving of protection until proved guilty beyond the shadow of a doubt, and that hysterical red-baiting is undignified and shameful, we spend our days torn between indignation and misgivings and most often just wind up confused but uneasy. Here, again, there must be a great temptation for a true specialist, such as an engineer or a scientist, to withdraw into the protective and respectable cocoon of his immediate task and leave to others so inclined the vigilant defense of the republic. Yet to do so is to assume the spurious mantle of a protected class. At this point again, our witness is Emerson:

"Fear is a thing which a scholar by his very function puts behind him. Fear always springs from ignorance . . . It is a shame to him if his tranquillity, amid dangerous times, arises from the presumption that his is a protected class."

The true professional man, if he values his integrity, will not compromise such an issue. He cannot, it seems to me, if he wants to keep his self-respect. I have one such example to cite; perhaps some of you are familiar with it.

Several days ago, in Seattle, six professors at the University of Washington, all with tenure rights, were tried before the regents of the university in regard to their relations with the Communist party. Three of them were dismissed. Watching this sober, strange, and rather tense spectacle were all kinds of Americans, like ourselves, torn between the issue of the defense of academic freedom and the issue of the defense of our political and economic institutions. The issues were complex, as is always the case in such affairs, but the procedure was orderly in the extreme. In reading the newspaper accounts you quickly get the impression that all concerned were anxious to preserve both the spirit of justice and their own integrity, but that they were no less anxious to defend their country. Two of the professors admitted their membership in the party, and a third gave equivocal answers. On the clear note that this was to be no witch hunt, the trial proceeded.

It was made plain that nobody was going to be dismissed for his private beliefs, but those who sat in judgment had this burden: since the party itself is not illegal, they had to show that what is permitted in politics is not permissible in education. Both sides were in favor of academic freedom—but they had to decide what it meant. In one of the finest examples I have seen of an earnest, honest, satisfying statement, President Raymond B. Allen of the university said:

"That academic freedom must be maintained in any university worthy of the name is beyond question. But academic freedom consists of something more than merely an absence of restraints placed upon the teacher by the institution that employs him. It demands as well an absence of restraints placed upon him by his political affiliations, by dogmas that may stand in the way of free search for truth, or by rigid adherence to a party line that sacrifices dignity, honor, and integrity to the accomplishment of political ends."

Those are words in which I take great pride, merely as a fellow citizen of President Allen. They are words in which any professional man can take particular pride, because they embody a reasoned, intellectual, and courageous approach to a difficult problem.

I would not have you think that Communism offers the professional engineer his only opportunity to understand and to act, aside from the specific confines of his job, because there are many others in which by the very nature of his key position in our economic scheme he has a vested interest. The whole profit system is today being closely examined—in fact, cross-examined is a better term—by men who at times seem, either through ignorance or malice, fanatically eager to destroy it. This has all the earmarks of an attempt to commit suicide with a boomerang. The anti-trust laws are today being employed vigorously, abetted by conflicts and sweeping reversals in judicial interpretation, to raise questions of the most far-reaching economic importance to American industry. The whole question of the reorganization of the federal administrative machinery, with probable repercussions in the areas of tax structure, fiscal policy, and government control over business, is one that cries for consideration and expression by intelligent private groups who acknowledge an unpaid debt in public service. The list could be long, but it is not at all my intention to compile a list. I would not presume to be so explicit.

### BALANCE LEARNING WITH HUMAN EXPERIENCE AND APPLY IT TO COMMON GOOD

It was my thought to point out to you, as simply as possible, that curious parallel between your own position today, and that of the early American scholar, and to impress you with the worth and urgency of this examination of yourselves as responsible leaders in the modern community. Today you stand well at the head of those aggressive and important forces in American life which have by their very achievements added to their responsibilities.

Because of the framework within which these remarks have been cast, I have constantly been referring to the "scholar" and the "professional man." These are, of course, only synonyms in our everyday speech for a man who can be defined also by the much more elegant but exact term "thinking man." Professionalsm is not so much a matter of license, or definition, or ertification, as it is a matter of the way a man applies imself to the business of working and living. It is a natter of meeting ethical standards and balancing earning with human experience. It is a matter of openmindedness and voluntary acceptance of responsibility, ot only for his own performance but in some degree or that of others.

The entrance requirements for membership in the rofessional estate are nowhere near as rigid and ifficult to meet as are the requirements for maintaining hat membership, and that is as it should be. One of our abiding characteristics must be that "confidence n the unsearched might of man" which Emerson ecommended to his audience at Cambridge. And if you ave any doubt remaining as to the timelessness of the rofessional estate, its privileges and its duties, it hould be resolved by these words, significant to the nembers of the Phi Beta Kappa Society in 1837 and qually applicable to those of the American Institute f Electrical Engineers in the winter of 1949:

"If there is any period one would desire to be born in —is it not the age of Revolution; when the old and the ew stand side by side, and admit of being compared; when the energies of all men are searched by fear and by hope; when the historic glories of the old can be compensated by the rich possibilities of the new era? This time, like all times, is a very good one, if we but know what to do with it."

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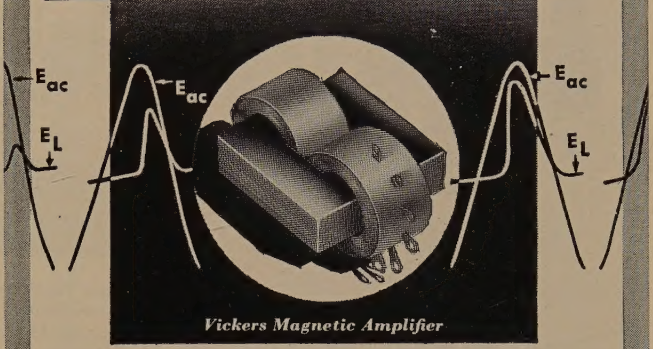

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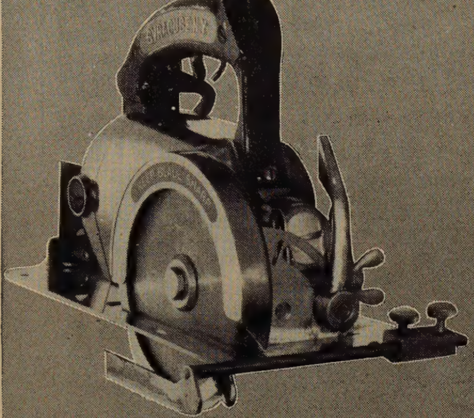

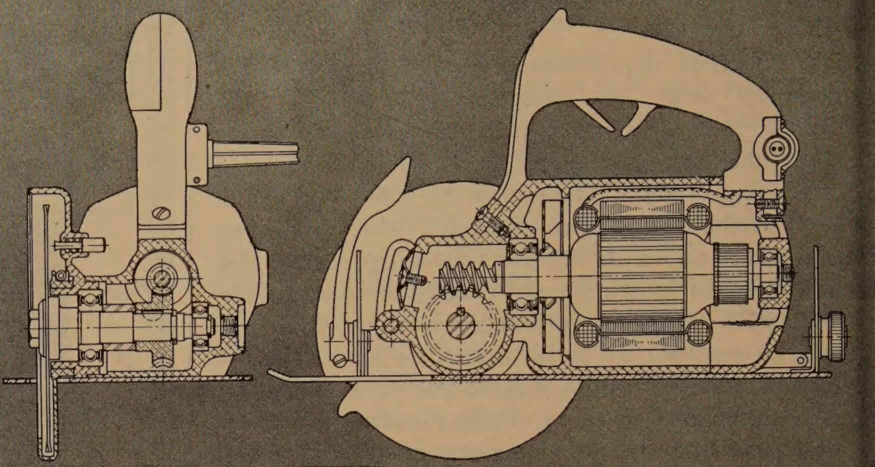

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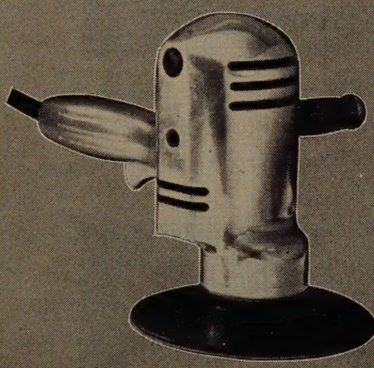

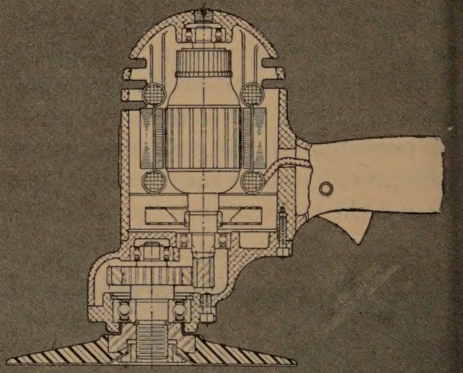

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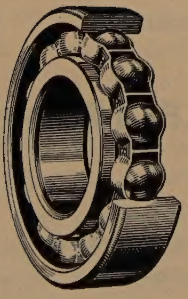

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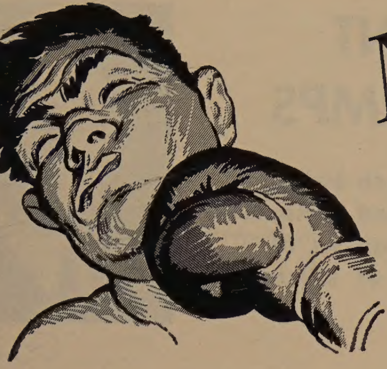

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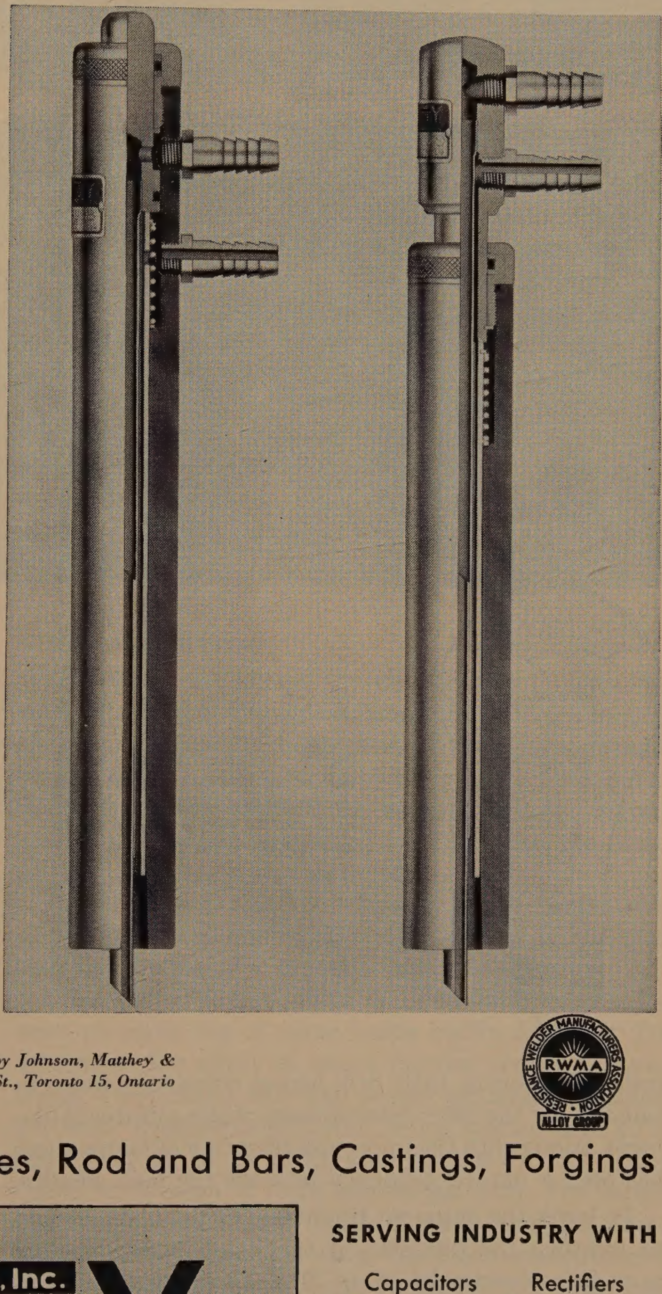

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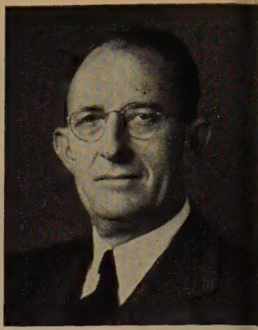

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General Electric Company

SINCE the invention of the incandescent lamp in 1879, by Edison, this type of lamp has passed through innumerable stages of development. The carbon filament, with its low efficiency of 2 to 3 lumens per watt, gave way to the osmium filament, and that to the tantalum filament, which in its turn was superseded by the tungsten filament after the difficulties of drawing tungsten wire had at last been overcome.

The tungsten-filament vacuum lamp had an efficiency nearly three times that of the carbon-filament lamp, but to improve it still further a higher operating temperature was required. This resulted in an early blackening of the bulb. Although the blackening could be prevented by filling the bulb with an inert gas, the heat lost by convection would have more than compensated for the gain until Langmuir's invention of the coiled filament in 1913. Still higher efficiencies were obtainable by the later development of the coiled-coil filament. Along with the improved efficiency of lamps there has been a natural tendency to make the bulb smaller.

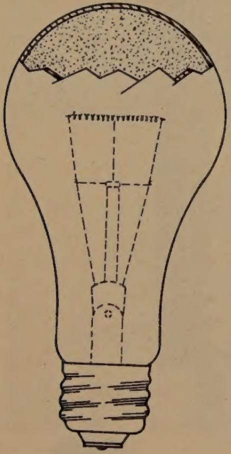

Fig. 1. Cutaway drawing of the bulb of the new incandescent lamp, showing at top a section of the fine silica coating that is applied to the inner surface of the glass

To lower the apparent brightness of the filament and to improve the diffusion of the light, inside frosting came into commercial use in 1925. This frosting reduces the light output only a negligible amount, but the degree of diffusion gained is not as much as is desirable for the present type of lamps, which have much smaller bulbs. The obtaining of that desired higher degree of diffusion necessitates the use of white or opal glass, or the application of a diffusing coating on either the inner or the outer surface of the bulb.

### METHODS OF OBTAINING LIGHT DIFFUSION

Light-diffusing bulbs have been produced by use of glass which, in its making, is rendered opalescent by the addition of fluorides or phosphates. Such glass is expensive and its light absorption is so high as to result in a 25-to-30-percent loss of light if the filament is completely masked.

Light diffusion obtained by applying a white enamel coating on the exterior surface is rather expensive and causes a loss of light of 12 to 20 percent. The application of this coating to the interior surface of bulbs does not cause as much light loss—only 5 to 8 percent—but results in very much weakened bulbs; this, in turn, results in high shrinkage in lamp making and handling.

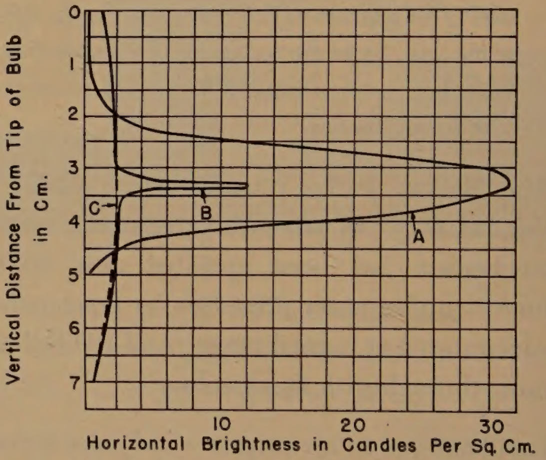

Fig. 2. Comparative curves of brightness of 100-watt tungsten-filament lamps: Curve *A* represents light distribution from a standard inside-frosted lamp; Curve *B*, from a lamp having a silica-coated clear-glass bulb; Curve *C*, from a lamp with silica-coated inside-frosted bulb

Inside frosting has been the lowest-cost and the most widely utilized process for the purpose. While the light loss by that frosting is small and the amount of diffusion is substantial, the diffusion characteristics of the new inside coating described in this article far surpass those of the inside frost.

### NEW METHOD OF COATING LAMP BULBS

The new method applies to the interior surface of bulbs (which is the best place to apply any coating) a

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Fig. 3. Three 100-watt incandescent lamps before use: (1) clear-glass; (2) inside-frosted; (3) inside-frosted inside-silica-coated, which produces a soft white light and gives all objects a natural, pleasing illumination

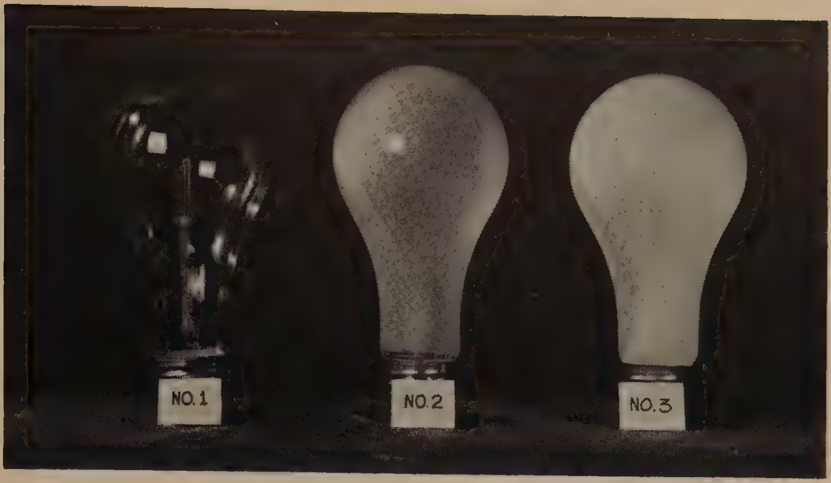
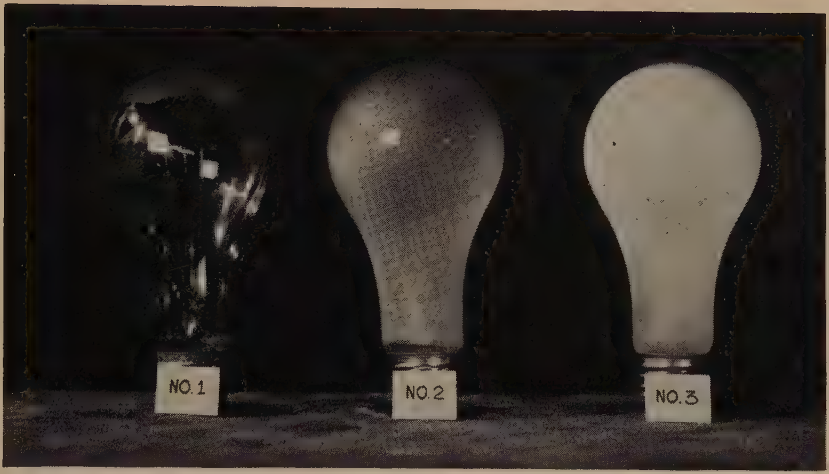


Fig. 4. Comparative blackening of the lamps shown in Fig. 3 after operation for two-thirds of their life



pure silica coating of extremely fine texture, almost completely masking the incandescent filament. In FIG. 1 is shown a cutaway illustration of a 100-watt incandescent lamp that has this new diffusing means.

One feature of the new method is that the thickness, or density, of the silica coating can be very much increased without affecting the uniformity of the illumination or greatly reducing the efficiency. The coating has no adverse effect on the strength of the bulb or on the operation of the lamp. Also, as can be seen in FIGS. 3 and 4, the silica-coated bulbs show less blackening during the life of the lamp than do clear-glass or inside-frosted bulbs.

TABLE I

EFFICIENCY IN LUMENS PER WATT

(Averages based on large numbers of lamps)

| Clear-glass Lamps | Inside-frosted Lamps | Clear-glass Lamps with Interior Coating of Silica | Inside-frosted Lamps with Interior Coating of Silica |
|---|---|---|---|
| 16.4 | 16.2 | 15.7 | 15.7 |
| to | to | to | to |
| 16.6 | 16.4 | 15.9 | 15.9 |

## LAMP PERFORMANCE

In Table I are shown the comparative lumens-per-watt efficiency of clear-glass lamps and of lamps having the named light-diffusing means. All these incandescent lamps were of 120-volt 100-watt rating, were made under similar circumstances, were 88 percent argon- and 12 percent nitrogen-filled, and included the same physical features except as noted.

It will be seen that the efficiency of the lamps with silica coatings is remarkably high in view of the fact that the coatings are almost completely diffusing.

From 40 to 80 milligrams of silica particles is sufficient to make one of those bulbs highly diffusing. To determine the effect of much heavier coatings, some lamps were coated with 280 to 560 milligrams of silica per bulb. Inside-frosted lamps, when silica-coated to a density of 10 to 20 milligrams per square inch, produced an average of 15.79 lumens per watt. For lamps of clear glass with heavy inside silica coating, the average was 15.73 lumens per watt. For inside-frosted lamps with no coatings, the average in lumens per watt was 16.60. The average loss in lumens per watt was 0.87, or 5.3 percent, for silica-coated clear-glass bulbs and 0.81 lumens per watt, or 4.9 percent, for the silica-coated inside-frosted bulbs.

The high degree of diffusion of bulbs coated by the new process is illustrated in FIG. 2 by the curves of brightness of 100-watt tungsten-filament lamps. These

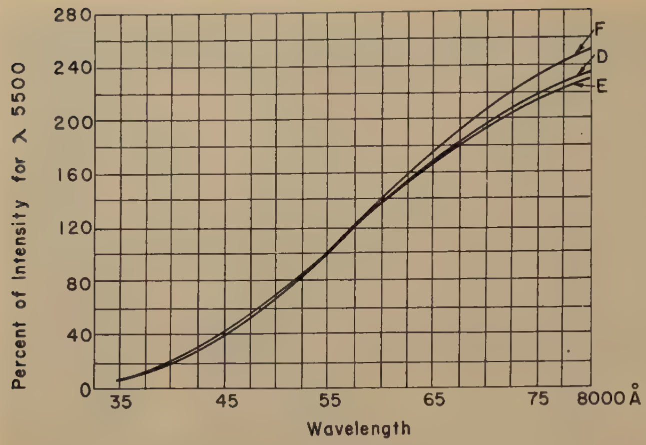


Fig. 5. Radiation curves for 100-watt tungsten-filament lamps with (Curve *D*) standard inside-frosted bulb, (Curve *E*) inside-frosted silica-coated bulb, and (Curve *F*) clear-glass silica-coated bulb show light distribution by all to be similar in intensity

curves were plotted from measurements of horizontal brightness, in candles per square centimeter, against the distance in centimeters from the tip of the bulb along a vertical line in front of the lamp. The measurements were made in a vertical plane through the lamp axis, and perpendicularly to the plane of the leads shown in Fig. 1. Curve *A* represents light distribution from a standard inside-frosted lamp; Curve *B*, from a lamp having a silica-coated clear-glass bulb; and Curve *C*, from a lamp having a silica-coated inside-frosted bulb.

As can be seen from those curves, the maximum brightness of the silica-coated clear-glass lamps is about 38 percent of that of the inside-frosted lamps, while that of the silica-coated inside-frosted lamps is only about 6 percent. The exact figures will depend upon the thickness and character of the coatings.

Measurements made on lamps of the same rating and type but with clear-glass bulbs showed an average maximum brightness of 1289 candles per square centimeter. The maximum brightness of the silica-coated clear-glass lamps and the silica-coated inside-frosted lamps is about 0.9 percent and 0.15 percent, respectively, of that of the clear-glass lamps.

Additional data on the light loss and maximum brightness of lamps is given in Table II.

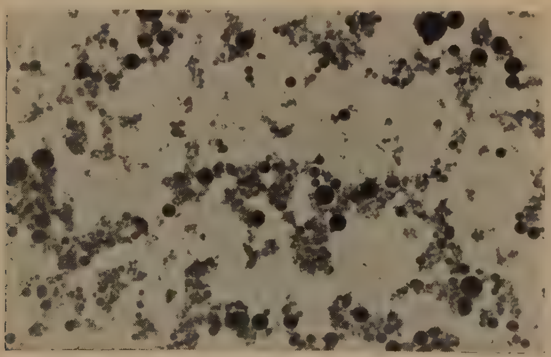


Fig. 6. Electron micrograph (×10,000) of silica coating from the inside surface of an A-21 bulb, showing configuration of the particles. This coating weighed 41 milligrams; average diameter of the particles was 2400 Ångstrom units

Fig. 5 shows spectral distribution curves of radiation emitted perpendicularly to the plane of the leads from 100-watt tungsten-filament lamps with and without silica coatings. Curve *D* represents distribution from a standard inside-frosted lamp; Curve *E*, from an inside-frosted lamp with silica coating; and Curve *F*, from a clear-glass lamp with silica coating. It is apparent that the light distribution by all these lamps is quite similar.

## PARTICLE SIZE AND SHAPE

A coating in an A-21 bulb weighed 41 milligrams and the particles had an average diameter ($d_3$) of 2400 Ångstrom units, the maximum diameter being 4500 Ångstroms, and the minimum diameter being less than 40 Ångstroms. These measurements were made in accordance with the method outlined in Chamot and Mason's *Handbook of Chemical Microscopy*, Vol. 1. Fig. 6 is a reproduction (×10,000) of an actual electron micrograph of the silica coating from the inside surface of a bulb, and shows the configuration of the particles as mechanically suspended in nitrocellulose for electron-microscope study. Fig. 7 (×20,000) shows the random distribution of the silica particles and the chain-like arrangement.

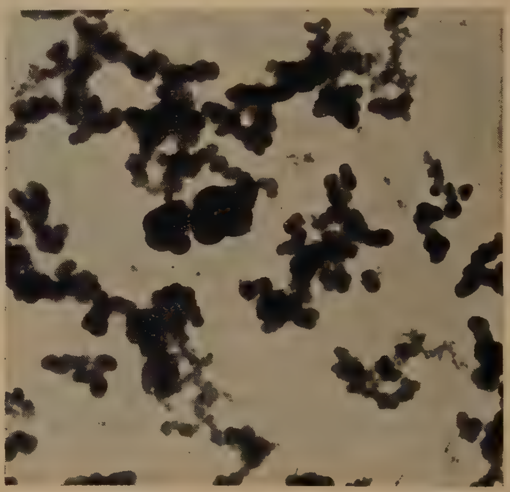


Fig. 7. Random distribution and chain-like arrangement of the particles (×20,000) in the coating are here apparent

In another instance the weight of the coating in an A-21 bulb was 40 milligrams and the particles had an average diameter ($d_3$) of 4300 Ångstroms, the maximum diameter being 7150 Ångstroms, and the minimum diameter 100 Ångstroms. Fig. 8 is a reproduction of an electron micrograph (×10,000) of the silica coating. This bulb was considerably more diffusing than the former.

The frequency of the occurrence of the particles in any given size classification for these coatings is approximately as shown by the curve in Fig. 9.

## FILLING WITH ARGON

The use of a silica coating, to diffuse the light output and reduce the maximum brightness of a lamp, results in no loss in the over-all efficiency (lumens per watt) of

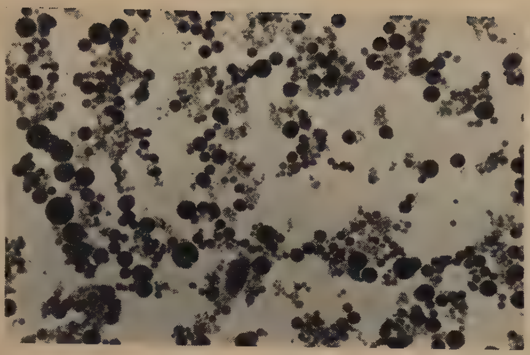


Fig. 8. This coating—weighing 40 milligrams, its particles (×10,000) averaging 4300 Ångstroms in diameter—is considerably more diffusing than that shown in Fig. 6 and 7

coiled-coil incandescent lamps. The loss that might be expected is completely recovered by the use of filling-gas compositions which in the past have been considered impractical in lamps having concentrated filaments.

In spite of the high thermal conductivity of nitrogen, the use of this gas has formerly been deemed necessary because of its high breakdown voltage. The breakdown-voltage of pure nitrogen is about ten times that of pure argon under the same conditions. A composition of 90 percent argon and 10 percent nitrogen has a breakdown voltage that is four times that of pure argon. To obtain freedom from internal arcs during rough handling of coiled-coil lamps that do not have the silica coating, use is made of a filling gas consisting of 88 percent argon and 12 percent nitrogen.

A large number of lamps that are not inside-silica-coated arc over internally. By the use of a filling atmosphere consisting essentially of an inert gas such as argon, krypton, or xenon, or a mixture of them, in combination also with the silica coating, the arc discharges across the filament terminals are eliminated. Thus, the lamp filaments can be operated at higher temperature, with resulting increase in lamp efficiency and light output. So far it has been practical to employ in these lamps an inert-gas mixture consisting of 98 percent argon by volume and 2 percent nitrogen.

In tests of lamps that had no silica coating but were inside-frosted and filled with 98 percent argon and 2 percent nitrogen, one third of the lamps developed internal arcs under the fragility tests, wherein lamps are bumped and lighted. In similar tests on the same number of lamps, identical to those in the other test except for the addition of an internal coating of silica, no lamps showed internal arcing. The results of the latter test are representative of those of a large number of tests conducted later to determine whether the silica coating prevents the internal arcing of such lamps.

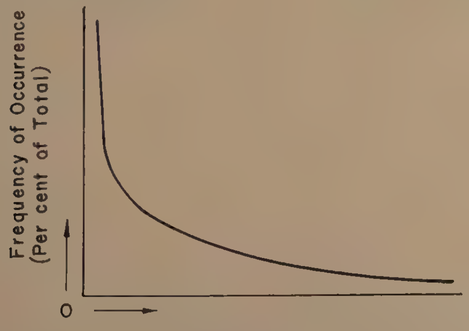


Fig. 9. Approximate variation of frequency of occurrence with size of particle for silica coatings

ADVANTAGES OF THE NEW LAMP

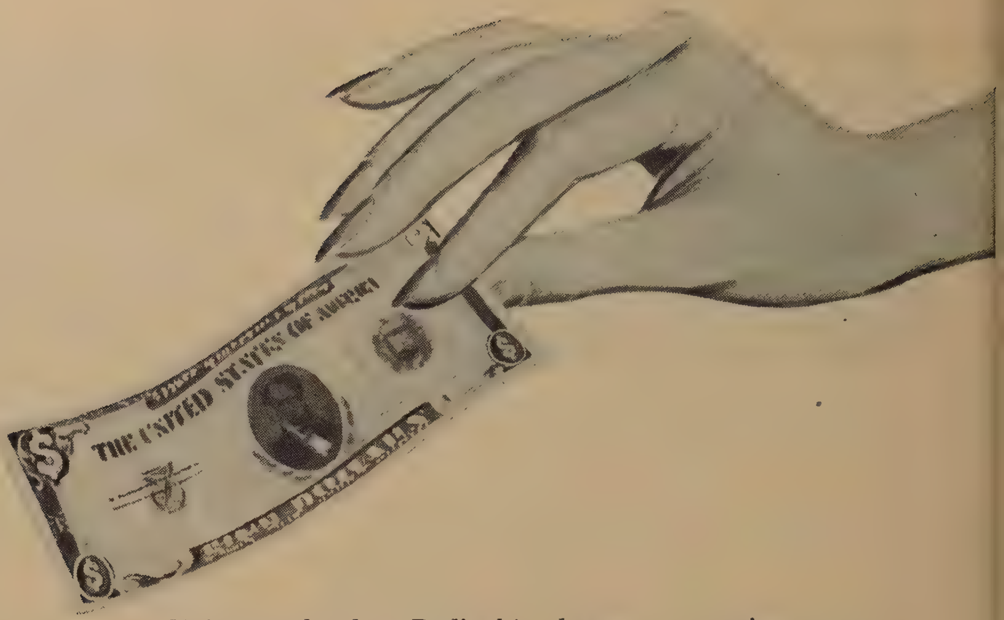
The new lamp is a convenient light source in which low brightness has been attained with no loss in light. When used in shades and reflectors, it will give no sharp shadows at the cut-off line. The light is more uniform and is more usable because bright spots and shadows are smoothed out.

TABLE II

LIGHT LOSS AND AVERAGE MAXIMUM BRIGHTNESS OF VARIOUS LIGHT SOURCES

| Light Source | Light Loss (Percent) | Average Maximum Brightness (Candles per sq cm) |
|---|---|---|
| 60-watt clear-glass lamp | 0 | 550 to 650 |
| 60-watt inside-frosted lamp | 0 to 0.5 | 8 to 12 |
| 60-watt outside-frosted (acid) | 3 to 5 | 5 to 8 |
| 60-watt opal-glass (heavy) | 16 to 25 | 3 to 6 |
| 60-watt opal-glass (light) | 8 to 12 | 10 to 15 |
| 60-watt outside-white (spray) | 16 to 25 | 3 to 5 |
| 60-watt outside-white (enamel) | 10 to 15 | 3 to 8 |
| 60-watt inside-white (spray) | 4 to 12 | 6 to 12 |
| 100-watt clear-glass lamp | 0 | 1300 |
| 100-watt inside-frosted | 0.2 to 0.5 | 32 |
| 100-watt clear-glass, silica-coated inside, 98% argon | 0 | 11 |
| 100-watt inside-frosted, silica-coated inside, 98% argon | 0 | 2 |
| Other light sources | | |
| Kerosene flame (flat-wick) | | 1.2 |
| 50-watt clear-glass carbon-filament lamp | | 55 |
| Clear sky (average) | | 0.4 |
| Sun as observed at earth's surface | | 165,000 |

Certainly, since the introduction of the coiled-filament gas-filled lamp in 1913, a lamp having the characteristics of the new product has been desirable and much sought after. In FIG. 3 were shown three 100-watt incandescent lamps before use: (1) a clear-glass lamp; (2) an inside-frosted lamp; and (3) an inside-frosted inside-silica-coated lamp. The same lamps, after operating for two-thirds of their life, were pictured in FIG. 4 to indicate their comparative blackening. Because of the silica-coated lamp's low rate of blackening and because of its whiteness—either lighted or unlighted—it can be used with good appearance in conjunction with fluorescent lamps. Its light is soft white in color and gives all objects a natural, pleasing illumination.



# *it's the kitty that counts*

Ma's sugar bowl, or Dad's shirt drawer, or a savings account, the family kitty is a wonderful gimmick. It tells us just how much we've got to go on.

You'd kick up a fuming fuss, if the government were to pile on tax after tax so you'd have nothing left over from your earnings to put into the kitty.

Just think . . . nothing to stash away for a rainy day, a new car, some new furniture, junior's education.

Rough? Well, suppose you headed up a business. A business needs a kitty too. A kitty to help you pay off stockholders. A kitty to cushion you against the bumps of slumps and setbacks. A kitty to dip into so you'd be able to expand, build new plants, install new machinery, make jobs for more men.

The word for the contents of the kitty in business is — profits.

Business profits keep 60-million Americans on payrolls. Business profits keep wage levels high. Business profits make possible all our family kittys and the security they imply.

Yet the aim in some quarters is to tax profits to the vanishing point. Such taxes may offset a staggering government indebtedness . . . temporarily! Sooner or later, it can only lead to — government seizure of all individual possessions . and the banishment of all personal rights.

**SHERRON ELECTRONICS CO.**

Division of Sherron Metallic Corporation

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MANUFACTURERS OF ELECTRONIC DEVICES AND SHEET METAL FABRICATION

# LIGHTNING PROTECTION OF METALCLAD SWITCHGEAR AND UNIT SUBSTATIONS CONNECTED TO OVERHEAD LINES

**Factors in selecting types of arresters and their most effective location for equipment served with and without continuous metallic-sheath cable. Included are specific arrester application data, and the answers to such questions as: "How long is a short cable?" and "What length exceeds a minimum length?" Summary of recommendations**

By Committee on Application of Lightning Arresters to Switchgear*
General Electric Company

METALCLAD switchgear and unit-substation switchgear, when connected to circuits exposed to lightning, should be protected by lightning arresters properly installed. These switchgear equipments are designed for circuit voltages from 2400 to 13,800 with power circuit breakers having interrupting ratings from 50,000 to 500,000 kva. Lightning exposure of these equipments exists when the equipments are connected to overhead lines, either directly or through any kind of cable, reactor, or regulator. Depending on the method of connection, the lightning-protection requirements may differ.

Analysis of any lightning-protection problem requires an evaluation of: (1) the impulse-protective characteristics of the arresters that are to be used; (2) the demonstrable impulse test levels of the apparatus to be protected; and (3) the necessary margin of protection between those levels.

### LIGHTNING ARRESTERS PROTECTIVE CHARACTERISTICS

For the application of surge protection to switchgear, the valve-type arrester with its dependable and predictable characteristics is the type to use. Two designs of valve-type arresters are the Thyrite station type and the pellet distribution type. The Thyrite station-type arrester has the better protective characteristics in addition to higher discharge-current capacity. It should be used in outdoor or indoor substation installations and in metal enclosures. A porcelain-top Thyrite station-type arrester is available for use in areas where space is at a premium. These arresters can be mounted on minimum centers with adequate electrical spacing.

The characteristics of valve-type arresters, both distribution type and station type, are given in Table I. The maximum levels for co-ordination listed in the table are those on which it is believed the analysis of the protection problem should be based.

TABLE I: PROTECTIVE CHARACTERISTICS OF VALVE-TYPE LIGHTNING ARRESTERS

| Arrester Type | Arrester Rating (kv) | Average Industry Values AIEE Sparkover (kv) | Maximum Protective Levels for Co-ordination (kv)* |
|---|---|---|---|
| Distribution | 3 | 17.4 | 22 |
| | 6 | 35 | 42.5 |
| | 9 | 48.7 | 60 |
| | 12 | 60.6 | 74 |
| | 15 | 69.1 | 81.5 |
| Station-type | 3 | 13 | 15 |
| | 6 | 23 | 25 |
| | 9 | 35 | 37 |
| | 12 | 43 | 52 |
| | 15 | 53 | 64 |

* Levels for co-ordination are chosen as average industry sparkover values with recognized industry plus-tolerances. Maximum IR voltages at discharge currents expected in service are equal to or less than the levels chosen for co-ordination.

### IMPULSE TEST LEVELS OF METALCLAD SWITCHGEAR

Industry standards now call for a basic insulation level (BIL), on a 1½×40 microsecond full-wave basis, of 60 kv for 4160-volt-class switchgear equipments and 95 kv for 13,800-volt-class equipments.

The insulation of metalclad switchgear is composed of air and many types of solid insulation. The volt-time curve of the composite equipment is considered flat for co-ordination purposes, and it is rationally assumed to be equal to the basic insulation level of the equipment.

### LIGHTNING PROTECTION FOR METALCLAD SWITCHGEAR

#### *With Roof-entrance Bushings*

On switchgear equipments with roof-entrance bushings, the incoming and outgoing lines terminate directly at the switchgear. The switchgear is therefore exposed to surges that can come in over the lines or result from a nearby direct stroke of lightning. Lightning arresters are definitely required at the switchgear for this arrangement of terminating overhead circuits.

The arresters can be mounted on the roof adjacent to the bushings or inside the metal enclosures. If the arresters are mounted on the roof, however, an extra ground bus is required, the expense of which makes the inside mounting a preferable location.

A schematic diagram of the arrester connections with the arresters grounded to the ground bus and

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* Membership of committee: E. M. Hunter, Chairman, Central Station Engineering; M. N. Halberg, Industrial Engineering; W. N. Gittings, Switchgear; D. C. Hoffmann, Switchgear; S. B. Howard, Lightning Arrester; and N. E. Dillow, Central Station Engineering Divisions.

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metal enclosure is shown in Table II together with a list of the lightning-arrester ratings required.

Occasionally the arresters are located on the first structure away from the switchgear. This structure also supports the lines from the switchgear section. The greater the circuit distance between the arrester and the equipment to be protected, the less effective the arrester protection will be. The greatest protection is obtained with the arresters connected in close shunt relation to the equipment to be protected, and for this reason the preferred and recommended arrester location is in the switchgear.

*Connected to Overhead Lines Through a Length of Cable Without a Continuous Metallic Sheath*

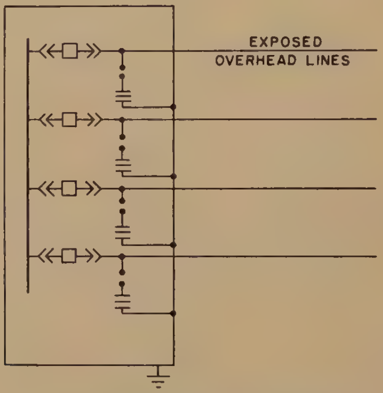
Arresters are required in the switchgear if the switchgear equipment is connected to overhead lines through a length of cable without a continuous metallic sheath. The absence of a continuous metallic sheath lengthens the effective separation between the switchgear and the arresters at the junction of the overhead line and cable. A second set of arresters at the terminals of the switchgear is then required to provide adequate protection. The arrester connections with the arresters grounded to the ground bus and metal enclosure are shown in Table II. These are the same as for equipments with roof-entrance bushings. This table lists also the lightning-arrester ratings required.

*Connected to Overhead Lines Through a Length of Continuous-metallic-sheath Cable*

Where the lightning exposure is from an overhead circuit with a section of continuous-metallic-sheath cable between it and the metalclad gear, surge-protection recommendations must take into account (1) the protective characteristics of the arrester to be applied at the junction of the cable and the overhead line, and (2) the impulse-voltage test level of the switchgear.

TABLE II

LIGHTNING ARRESTER APPLICATION TO METALCLAD SWITCHGEAR
DIRECTLY CONNECTED TO OVERHEAD CIRCUITS THROUGH ROOF ENTRANCE BUSHINGS
OR THROUGH NON-CONTINUOUS METALLIC SHEATH CABLE



ONE-LINE DIAGRAM OF SWITCHGEAR EQUIPMENT INDICATING ARRESTER CONNECTIONS IN SWITCHGEAR.

LIGHTNING ARRESTER APPLICATION

| RATING OF SWITCHGEAR | NOMINAL 3ø SYSTEM PHASE-TO-PHASE VOLTAGE (KV) | | ARRESTER RATING TO BE INSTALLED IN SWITCHGEAR |
|---|---|---|---|
| | GROUNDED NEUTRAL (1) | NON-GROUNDED NEUTRAL (1) | |
| 4.16 KV (60 KV BIL) | 2.4 OR 4.16 | 2.4 | 3 |
| | — | 4.16 | 4.5(2) |
| 13.8 KV (95 KV BIL) | 4.8 | — | 4.5 |
| | 6.9 | 4.8 | 6 |
| | — | 6.9 | 7.5(3) |
| | 11.5 | 6.9 | 9 |
| | 13.8 | 11.5 | 12 |
| | — | 13.8 | 15 |

(1) GROUNDED NEUTRAL AND NON-GROUNDED NEUTRAL SYSTEMS ARE DEFINED IN TERMS OF USUAL LIGHTNING ARRESTER APPLICATION PRACTICE. GENERALLY, A GROUNDED NEUTRAL ARRESTER CAN BE USED IF THE LINE-TO-GROUND FAULT CURRENT FOR ANY FAULT LOCATION IS NOT LESS THAN 60 % OF THE THREE-PHASE FAULT CURRENT.

(2) METALCLAD COMPARTMENTS OF 20 INCH WIDTH DO NOT PERMIT INSTALLATION OF STATION-TYPE ARRESTERS. FOR THESE APPLICATIONS A 3 OR 6 KV DISTRIBUTION TYPE ARRESTER IS INSTALLED IN THE SWITCHGEAR WITH A METAL BARRIER TO ISOLATE THE ARRESTERS FROM THE REMAINDER OF THE SWITCHGEAR UNIT.

(3) THIS RATING CAN BE APPLIED ONLY ON THOSE 6900 VOLT NON-GROUNDED NEUTRAL SYSTEMS WHERE LINE-TO-GROUND VOLTAGE WILL NOT EXCEED 7500 VOLTS UNDER ANY CONDITION OF OPERATION, INCLUDING LINE-TO-GROUND FAULTS AND OVERSPEEDING OF HYDROELECTRIC GENERATORS.

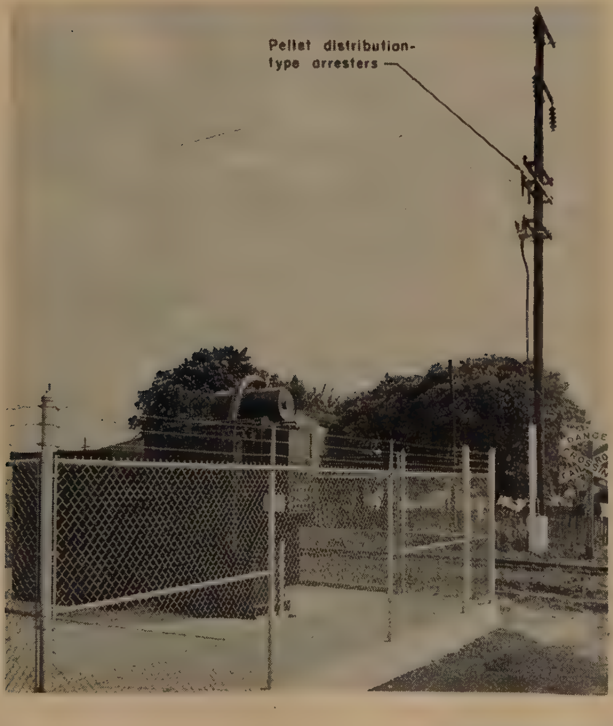


**Fig. 1.** Pellet arresters installed at junction of overhead line and cable with interconnection of arrester ground and cable sheath

The surge voltage at the junction of overhead line and cable is limited to the protective level of the arrester installed at that point. If an arrester is not installed at the switchgear end of the cable, the surge passing the arrester at the junction will double at the terminals of an open circuit breaker in the switchgear for most cable lengths encountered in service. This has been substantiated by investigations of surges in continuous metallic-sheath cable made on the transient analyzer.

Experience has shown that arresters generally are needed at both ends of cable lengths to eliminate failures from lightning. This is particularly true if the apparatus is below modern industry standards of impulse-test value.

## TABLE III

LIGHTNING ARRESTER APPLICATION TO METALCLAD SWITCHGEAR CONNECTED TO OVERHEAD CIRCUITS THROUGH CONTINUOUS METALLIC SHEATH CABLES

LIGHTNING ARRESTER APPLICATION

| RATING OF SWITCHGEAR | NOMINAL 3Ø SYSTEM PHASE-TO-PHASE VOLTAGE (KV) | | ARRESTER RATING INSTALLED AT JUNCTION OF CABLE AND OVERHEAD (KV) | ARRESTER RATING TO BE INSTALLED IN SWITCHGEAR (2) (KV) | SUGGESTED MAXIMUM LENGTH OF CABLE NOT REQUIRING ARRESTER IN SWITCHGEAR (FT.) |
|---|---|---|---|---|---|
| | GROUNDED NEUTRAL (1) | NON-GROUNDED NEUTRAL (1) | | | |
| 4.16 KV (60 KV BIL) | 2.4 OR 4.16 | 2.4 | 3 | NONE REQUIRED | ANY LENGTH |
| | | 4.16 | 6 | 4.5(3) | 10 |
| 13.8 KV (95 KV BIL) | 4.8 | – | 6(6) | 4.5 | 75 |
| | 6.9 | 4.8 | 6(6) | 6 | 75 |
| | – | 6.9 | 9(6) | 7.5(4) | 20 |
| | 11.5 | 6.9 | 9(6) | 9 | 20 |
| | 13.8 | 11.5 | 12 | 12 | SEE (5) |
| | – | 13.8 | 15 | 15 | SEE (5) |

(1) GROUNDED NEUTRAL AND NON-GROUNDED NEUTRAL SYSTEMS ARE DEFINED IN TERMS OF USUAL LIGHTNING ARRESTER APPLICATION PRACTICE. GENERALLY, A GROUNDED NEUTRAL ARRESTER CAN BE USED IF THE LINE-TO-GROUND FAULT CURRENT FOR ANY FAULT LOCATION IS NOT LESS THAN 60 % OF THE THREE-PHASE FAULT CURRENT.

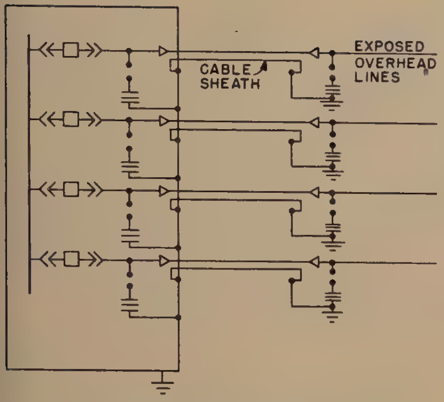
(2) ARRESTERS ARE REQUIRED IN SWITCHGEAR WHEN LENGTH OF CABLE BETWEEN LINE TERMINATION AND SWITCHGEAR EXCEEDS LENGTH TABULATED IN ADJOINING COLUMN.

(3) METALCLAD COMPARTMENTS OF 20 INCH WIDTH DO NOT PERMIT INSTALLATION OF STATION-TYPE ARRESTERS. FOR THESE APPLICATIONS A 6 KV DISTRIBUTION TYPE ARRESTER IS INSTALLED IN THE SWITCHGEAR WITH A METAL BARRIER TO ISOLATE THE ARRESTERS FROM THE REMAINDER OF THE SWITCHGEAR UNIT.

(4) THIS RATING CAN BE APPLIED ONLY ON THOSE 6900 VOLT NON-GROUNDED NEUTRAL SYSTEMS WHERE LINE-TO-GROUND VOLTAGE WILL NOT EXCEED 7500 VOLTS UNDER ANY CONDITION OF OPERATION, INCLUDING LINE-TO-GROUND FAULTS AND OVERSPEEDING OF HYDROELECTRIC GENERATORS.

(5) FOR THE RATING OF ARRESTER USED AT JUNCTION OF OVERHEAD LINE AND CABLE, THE MAXIMUM DISTANCE PERMITTED IS SO SHORT IT IS NOT PRACTICABLE TO LIST IN TABLE.

(6) INSTALLATION OF STATION-TYPE ARRESTERS OF THIS RATING AT THE JUNCTION DO NOT REQUIRE ARRESTERS IN THE SWITCHGEAR.



ONE-LINE DIAGRAM OF TYPICAL SWITCHGEAR EQUIPMENT INDICATING ARRESTER CONNECTIONS IN SWITCHGEAR. CABLES ARE THREE-CONDUCTOR TYPE.

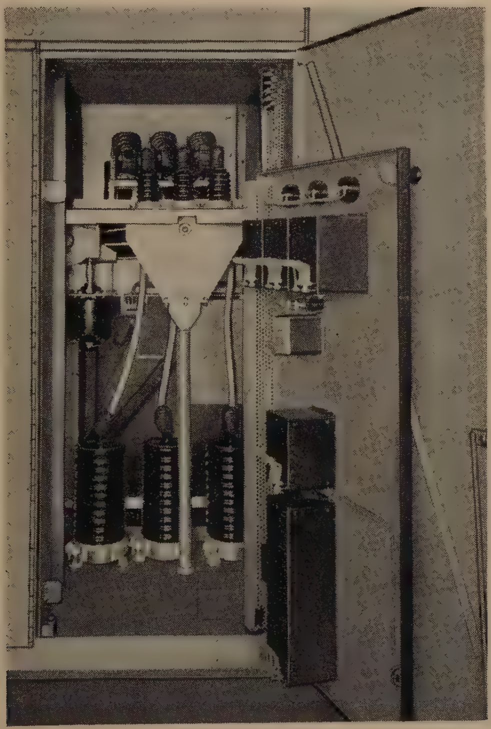


Fig. 2. Indoor design of station-type Thyrite arresters installed in switchgear enclosure

It appears reasonable to assume, however, that an arrester is not needed in the switchgear if (1) a valve-type arrester having the protective level listed in Table I is correctly installed at the junction of the cable and overhead line, and (2) the surge (equal in value to the protective level when reflected to double value at the switchgear end) is equal to or less than 80 percent of the switchgear BIL.

The lightning arrester at the junction of the cable and overhead line, to be correctly installed, must for safety reasons be connected to ground, and the arrester ground must be bonded to the cable sheath. The bonding to the sheath eliminates the influence of the arrester ground impedance, and makes the protection obtained independent of it. Investigations of a number of failures due to lightning have shown that otherwise adequate lightning protection was ineffective because the bond was not made between the cable sheath and ground. The cable sheath must, of course, be bonded to the switchgear frame at the equipment end.

A valve-type arrester of either the Thyrite station type or the pellet distribution type may be used at the line end of the cable. A typical installation of pellet arresters at the cable junction is illustrated in Fig. 1.

The following example illustrates the application of arresters to switchgear on a 4160-volt grounded-neutral system. A 3-kv distribution-type arrester might be used at the junction of the cable and overhead line. From Table I, the maximum impulse voltage at the junction is limited by this arrester to 22 kv. Under the worst conditions, the impulse voltage at the switchgear would be twice this value or 44 kv. This voltage is less than 80 percent of the 60-kv BIL of the gear, and it is concluded from this reasoning, that an arrester in the switchgear is not justified.

On the other hand, a 13.8-kv grounded-neutral circuit might be assumed to have a 12-kv station-type arrester at the junction of the cable and overhead line. Referring again to Table I, the maximum impulse voltage passing this arrester is 52 kv which when doubled at the switchgear becomes 104 kv. This value exceeds the 95-kv BIL of the switchgear. For this application, it must be concluded that arresters in the switchgear are required.

A tabulation of the analysis for various circuit voltages and conditions of neutral grounding is presented in Table III. The arrester connections for both line-end and switchgear-end units are also shown schematically with particular regard to arrester-ground interconnection. Porcelain-top station-type arresters installed in the switchgear enclosure are shown in Fig. 2.

In general, except for resistance-grounded or ungrounded 4160-volt circuits, the 4.16-kv-class equipments do not require lightning arresters in the switchgear. However, the 13.8-kv-class equipments should always include arresters except where the length of cable is less than the maximum suggested in Table III.

### LIGHTNING PROTECTION FOR UNIT SUBSTATIONS

If the transformer section of the unit substation has cover bushings for terminating the incoming line, lightning arresters preferably of the Thyrite station-type should be mounted as close as practical to the transformer with the arrester ground connected to ground and the transformer tank as shown schematically in Fig. 3. The Cover illustration shows a typical installation of arresters mounted on the transformer.

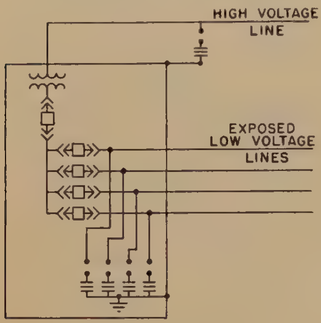


**Fig. 3.** One-line diagram of unit substation with four feeder breakers, showing high- and low-voltage arrester connections when lines terminate in bushings on unit

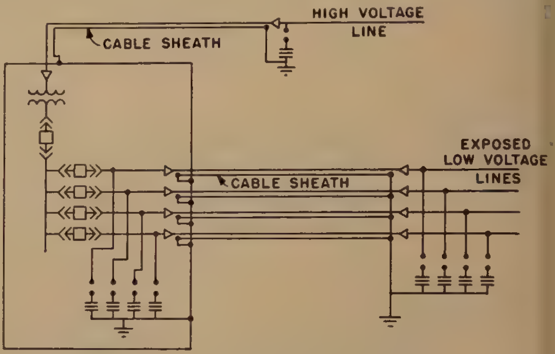


**Fig. 4.** One-line diagram of unit substation with four feeder breakers, showing high- and low-voltage arrester connections when lines terminate in lengths of three-conductor cables

If the high-voltage terminal of the transformer is a cable pothead with a length of cable of the continuous-metallic-sheath type between the transformer and overhead line, arresters should be installed at the junction of the cable and overhead line with the arrester ground bonded to the cable sheath.

Additional arresters at the transformer end of the cable generally are not required, regardless of the cable length. The surge voltages applied at the transformer, in excess of the voltage limited by the arrester at the junction of cable and overhead line, are of relatively short duration and should be co-ordinated with the chopped-wave test level of the transformer.

For example, a 13.8-kv power-transformer winding has an impulse test level of 110 kv on the 1.5×40 microsecond full-wave basis and 130 kv on the chopped-wave basis. With properly installed 12-kv Thyrite station-type arresters at the line terminals of the cable, the maximum reflected voltage at the transformer would be approximately 104 kv. Accordingly, a transformer-cable termination with insulation co-ordinated with the transformer insulation should be adequately protected by the arrester at the junction of cable and overhead line as shown schematically in Fig. 4.

Cable which does not have a continuous metallic sheath should have arresters at both ends of the cable. Cable terminations on transformers are often oil-insulated. However, whether air- or oil-insulated, space for arresters is difficult to provide. Use of such cables is therefore questionable when lightning exposure exists.

With lightning arresters correctly applied to the high-voltage side of the transformer, experience has generally indicated that a second set of arresters at the low-voltage terminals of the transformer is not needed to protect either the transformer or switchgear, unless the low-voltage circuit is itself exposed to lightning.

Lightning protective equipment for the feeders of the switchgear sections of unit substations should be applied in the same manner prescribed for the protection of metalclad switchgear previously considered.

An exception to the mounting of arresters in the switchgear exists in the single-circuit unit substation. In these designs where roof bushings are used, arresters may be rack-mounted on the top of the switchgear compartment as illustrated in Fig. 5. This exception exists because the switchgear compartment is of welded construction, thereby eliminating the need for an extension of the ground bus to the arresters.

### GENERAL COMMENTS

The protective practices outlined for cable-entrance circuits have been based for the most part on three-conductor leaded cable. With this type of cable, it is permissible to ground both the line and switchgear ends of the sheath. This multiple grounding is not always permissible with single-conductor leaded cable because of the possibility of dangerous circulating currents in the sheath. Single-conductor cables should be directly grounded in the switchgear equipment. The arresters at the line end should be connected between the cable core and sheath, and the arrester ground made through an isolating gap. This will prevent circulating sheath currents. During lightning-surge discharges through the arresters, the isolating gap becomes conducting, permitting the discharge to pass directly to ground. Such an arrangement is indicated schematically in Fig. 6.

In applying arresters for cable-entrance circuits, the question is often asked, "How long is a short cable?" or, "What length exceeds a minimum length?" It is obvious that a cable length of only a few feet could hardly justify an arrester at each end. A suggested maximum length of continuous-metallic-sheath cable is listed in Table III. The suggested maximum length of cable not requiring a lightning arrester in the switchgear is predicated on a travelling-wave analysis assuming a wavefront of 1000 kv per microsecond arriving at the junction of overhead line (surge impedance of 500 ohms) and continuous-metallic-sheath cable (surge impedance of 30 ohms). The velocity of propagation of the surge in the cable is assumed as 600 ft per microsecond. To be practical, however, in the general application of metalclad switchgear or unit substations, the minimum circuit distance from the breaker terminals to the arresters at the junction of cable and overhead line is seldom less than seventy-five feet and more often is of the order of several hundred feet.

The reflection at the switchgear end of a cable of the voltage allowed by the arresters at the junction of cable and overhead line depends on the length of the cable and the wave shape of the incoming surge. The steeper the wave front and the longer the cable, the higher is the switchgear-end voltage up to a maximum of twice the arrester protective level. Attenuation and distortion of the wave in the cable is negligible for most cable engths considered. Generally, when the outgoing cable terminates in an overhead line, lightning protection as outlined in this article is required.

Circuits confined entirely to the interior of a building, such as an industrial plant, are not considered exposed and hence, ordinarily would not require lightning protection.

Space for a set of station-type arresters and a cable pothead is available in each outgoing feeder compartment of modern metalclad switchgear and unit substations. Arresters can be installed at the time the substation is energized or at some time in the future if the need for them should arise.

Many equipments are in service, however, where there is no space for arresters. Should the need for arresters become apparent in these older applications, protection comparable to that obtained by installing arresters in the switchgear can be realized. This is accomplished by installing, at the junction of the continuous-metallic-sheath cable and overhead line, a set of Thyrite station-type arresters and a set of Pyranol protective capacitors similar to the protective equipment furnished for a-c rotating machines. The Thyrite station-type arresters provide the best available in arrester protection, and the capacitors reduce the steepness of the entering surge so that the reflected voltage at the equipment end of the cable is kept to values usually considered safe.

Lightning arresters always should be connected to the line side of the circuit breaker to prevent reflection of impulse voltages at times when the breaker is in the open position. It is recognized that a breaker is normally closed and will be open only a very small percentage of the time it is in operation. However, it is most likely to be open when a lightning storm is over the area served by the substation, as feeder damage due to lightning may be the reason the breaker is open.

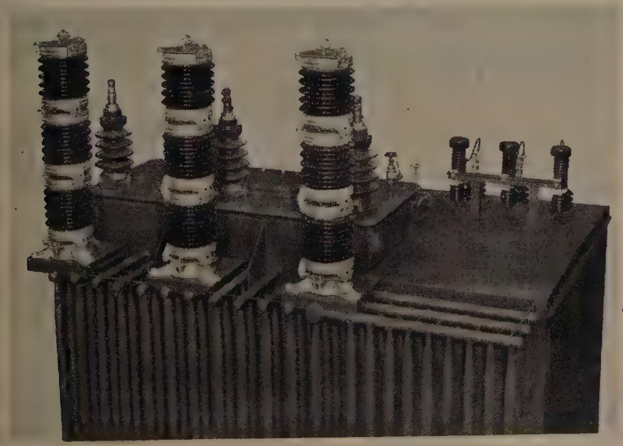


Fig. 5. Single-circuit unit substation with high- and low-voltage arresters mounted on the equipment

When applying a protective device, such as an arrester, it is always advisable to so locate it in the circuit as to take advantage of short-circuit protective devices, such as relays and circuit breakers. In the remote possibility of arrester damage, the fault will be automatically cleared and isolated by the short-circuit protective equipment. The use of fuses in series with arresters is not recommended because an open fuse would nullify the presence of the arrester and would not normally be detected since there would be no obvious curtailment of service; for example, that which occurs when a potential-transformer fuse blows. When the arresters are located on the line side of the feeder breakers, they are in the relay-protective zone of the feeders. Consequently, in this instance, short-circuit protection is provided.

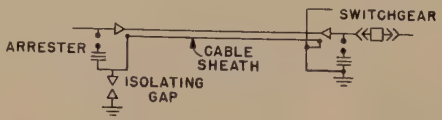


Fig. 6. Single-conductor cable termination with arrester ground terminal connected to cable sheath only with isolating gap between sheath and ground

Rotating machines connected to circuits exposed to lightning either directly or through transformers require lightning protection. Thyrite station-type arresters and Pyranol protective capacitors should be used. The preferred location of this protective equipment is at the terminals of the machine to be protected.

### SUMMARY

Metalclad switchgear and unit substations connected to exposed overhead circuits either directly or through a length of cable require lightning protection.

Equipments connected to overhead circuits through continuous-metallic-sheath cable generally should have arresters in the switchgear if equipment is in the 13.8-kv class, in addition to properly installed arresters at the junction of the cable and overhead line. The exception to this is where the cable length is quite short. The 4.16-kv class of equipment, for most applications, does not require arresters in the switchgear. Exception to this is the 4160-volt ungrounded or resistance-grounded circuit which requires arresters in the switchgear.

Equipments connected directly to overhead circuits through roof-entrance bushings or by cables without a continuous metallic sheath require arresters at the switchgear where connection in close shunt relation to the switchgear to be protected is possible. The preferable location is in the metal enclosure.

Space for one set of valve-type arresters is a standard feature of design in modern metalclad switchgear. The space is adequate for porcelain-top Thyrite station-type arresters except in compartments of the 20-in. width.

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# PROTECTIVE ATMOSPHERES IN INDUSTRY . . . Part IV

## Combusted fuel gas—its uses and properties, costs, manufacture, and distribution. Methods and equipment used in the purification of gases

By A. G. HOTCHKISS and H. M. WEBBER
Industrial Heating Divisions, General Electric Company

### COMBUSTED FUEL GAS

The most widely used gas among all the available protective atmospheres is combusted fuel gas. This is largely because raw materials to make it are readily available, the results are generally excellent, and the gas is inexpensive. Hydrocarbon gases, such as coke-oven gas, natural gas, propane, or butane, are commonly used and burned in an atmosphere-gas converter, such as the one illustrated in FIG. 24. Properties of the combusted gas vary as the amount of air supplied for combustion is changed. Partially burned gas is the more commonly used, but completely burned gas also has some applications.

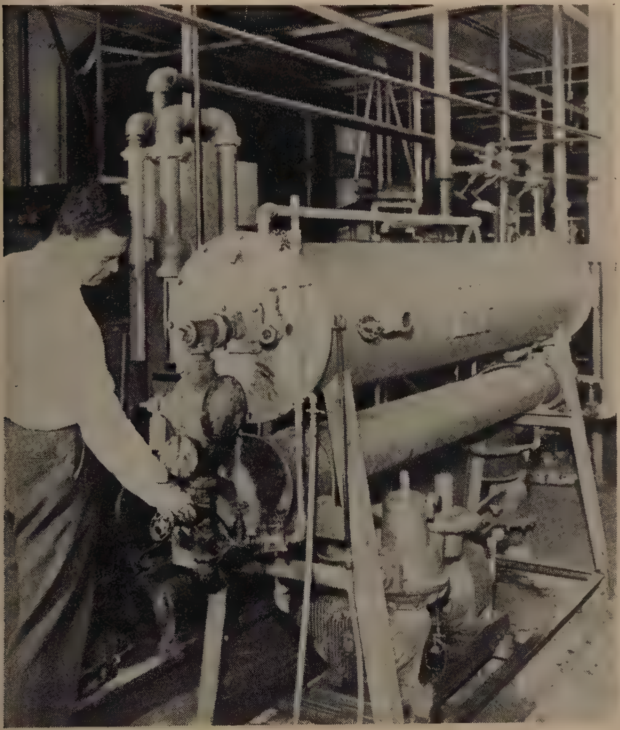

Fig. 24. Atmosphere-gas converter rated 1500 cfh. Such units are widely used for providing inexpensive protective atmospheres by partial or complete combustion of hydrocarbon fuel gases

Partially burned fuel gas is moderately reducing because it contains appreciable amounts of hydrogen and carbon monoxide which are reducing to oxides of iron and copper at elevated temperatures (Table III, Part II, Dec. 1948). This gas, then, is excellent for bright-annealing, normalizing, hardening, furnace brazing, and sintering, and it normally produces clean, bright work. It will, however, decarburize medium- and high-carbon ferrous metals, as a result of which other gases (which will be presented in a later part) are sometimes considered more suitable.

Completely burned fuel gas is commonly used for bright-annealing of copper; annealing of brass and bronze; silver-brazing of copper, brass, or bronze; prevention of oxides in storage of paints and varnishes; bubbling batches of synthetic resins, synthetic varnishes, and bodying oils during cooking; and protection against oxidation of rubber bags used in the curing of tires and of fruit juices in cans. Other uses are for fire prevention and fire extinguishing in the paint and varnish industry, and for explosion prevention of a variety of dusts or finely powdered materials in the drug, chemical, and other industries.

The foregoing constitutes only a partial list of uses of combusted fuel gas for protective atmospheres in industry, but it gives an idea of the diversity of its applications. New uses are continually arising in the usual search for lower-cost production methods. In such applications, combusted fuel gas either results in an improvement in quality where a protective atmosphere was not formerly used, and possibly an attendant cost reduction, or it is employed as a substitute for some other gas, such as hydrogen, nitrogen, or carbon dioxide, to give equal or better results at lower cost.

#### PROPERTIES OF LOW-RATIO COMBUSTED GAS

The low-ratio atmosphere-gas converter can be operated over a range to give a variety of mixtures of output gas. The most commonly used mixture is one containing about 15 to 18 percent hydrogen, 10 to 14 percent carbon monoxide, 4 to 5 percent carbon dioxide, 0.0 to 2 percent methane, and the remainder nitrogen. It has 0.0 percent oxygen and generally is saturated with water vapor at about 10 F above the temperature of the available cooling water used in the surface cooler of the converter. Because of its hydrogen and carbon-monoxide content, this gas is moderately reducing on oxides of various metals, such as iron and copper, at elevated temperatures.

If the fuel gas contains sulfur, the combusted gas will also be contaminated with sulfur. This usually occurs with coke-oven gas, but it is uncommon in the other hydrocarbon gases. Sulfur in the amounts permitted in city-gas systems, occurring in combusted gas, ordinarily is not harmful to ferrous metals, but it has a tendency to blacken copper and silver and to embrittle nickel. Consequently, when treating such metals, sulfur, if present, is usually removed.

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This article is so paged that without mutilating other articles, it can be readily removed for filing as a group of full-size consecutive pages.—EDITOR

The moisture content of the gas described usually causes no difficulty, and bright work is obtained from furnaces using it as a protective atmosphere, particularly in continuous or intermittent treatment of short-time duration. For bright-annealing large batches of steel, such as coiled strip, however, which involves relatively slow cooling rates, the moisture content is commonly reduced by refrigeration, particularly in geographical areas where the cooling-water temperature is high in the summertime. In a few localities this cooling-water condition dictates refrigeration of the gas, even for short-cycle treatments.

Where surface decarburization of medium- or high-carbon steel is a factor, complete removal of the water vapor and carbon dioxide is necessary. This phase of the application will be considered at greater length in another part of this serial.

Perhaps it should be emphasized here, however, that little benefit in this direction can be obtained by completely removing only one of these two constituents—either water vapor or carbon dioxide—because, as explained under the water-gas-reaction Equation (13), Part II, equilibrium will ultimately be established and the constituents removed will reappear in the furnace atmosphere.

Because of its relatively low hydrogen content, the partially burned combusted gas described is only mildly inflammable and explosive. The gas described has a specific gravity of about 0.86. Because it approaches the weight of air, a protective atmosphere of this gas can be maintained in furnaces without much difficulty; for example, in the mesh-belt conveyor-type furnace in which there is considerable opportunity for infiltration of air at the continuously open end doors. The thermal content is about 96 Btu. As a result, some heat is developed at door openings where the gas burns, but the amount is less than with higher-hydrogen gases. The thermal conductivity with respect to air is only about 1.9, which has a favorable effect on reduction of thermal losses from the furnace, and gives lower heating and cooling rates of the work than are obtained with higher hydrogen gases.

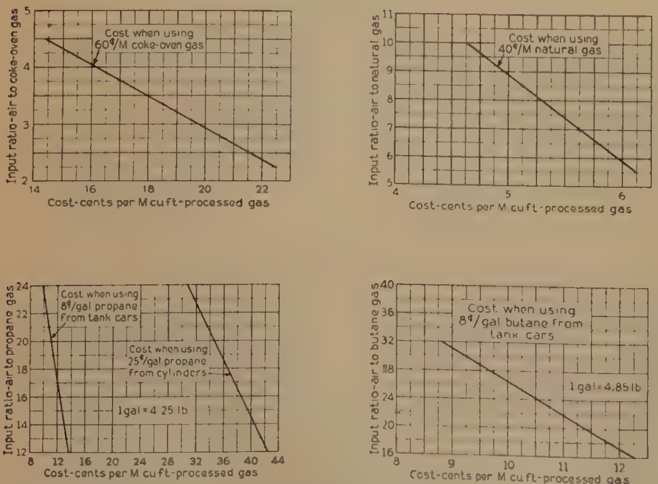

**Fig. 25. Cost of processed gas from atmosphere-gas converters at various input air-gas ratios**

PROPERTIES OF COMPLETELY COMBUSTED FUEL GAS

The high-ratio-type atmosphere-gas converter has a range of operation, but the most common condition is to operate at almost complete combustion. In that instance, the combusted-gas analysis is about 0.7 percent hydrogen, 0.7 percent carbon monoxide, 10 to 13 percent carbon dioxide, and the remainder nitrogen. The gas contains no oxygen or methane. It is saturated at about 10 F above the cooling-water temperature. Because of its extremely low hydrogen and carbon-monoxide content, the gas is considered to be practically inert, good evidence of which is obtained in the bright-annealing of copper containing copper oxide. When bright-annealed in this gas, no embrittlement due to formation of water vapor at the grain boundaries by a combination of hydrogen and oxygen takes place, and the copper is reliably ductile. Other indications of this inert property are evident in the list of applications given earlier.

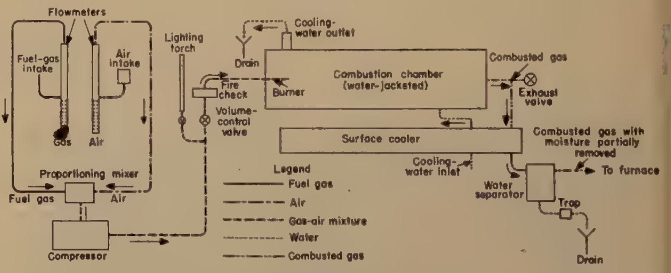

**Fig. 26. Typical flow diagram of atmosphere-gas converter**

Since the gas described is commonly employed for the bright-annealing of copper, sulfur removal is necessary as previously mentioned to avoid discoloration of the copper, if the fuel gas burned contains sulfur compounds. It is rather uncommon to reduce the water-vapor content of this gas because, for most applications in which the gas is suitable, water vapor is not troublesome.

When completely combusted, the gas described is not inflammable nor explosive when mixed with air. Its specific gravity is about 1.03, which means that it is practically the same weight as air. Also, its thermal conductivity is very low (0.99 with respect to air).

COST

The cost of prepared gas from an atmosphere-gas converter is very low—only a fraction of the unit cost of the fuel gas reformed by the converter. For example, a converter supplying 1000 cfh to a furnace which is bright-annealing steel will operate on an input ratio of about 2½ volumes of air to one of coke-oven gas, and will consume about 360 cu ft of coke-oven gas each hour. Thus, the 1000 cu ft of prepared gas will actually cost only 0.360 times the cost of 1000 cu ft of coke-oven gas. If it is assumed, for illustrative purposes, that the cost of coke-oven gas is 60¢ per M cu ft, the converted gas will cost 0.36×60 or 21.6¢ per M.

The cost varies with the input ratio in accordance with the curves shown in FIG. 25. The upper lefthand curve is plotted for 60-cent coke-oven gas. If coke-oven gas costing more or less than 60¢ is used, the prepared-gas cost will be that shown on the curve, multiplied by the actual coke-oven-gas cost in cents and divided by 60. For example, at a ratio of 2½-to-1, with 70-cent coke-oven gas, the prepared gas will cost:

$$21.6¢ \times \frac{70}{60} = 25¢ \text{ per M cu ft.}$$

The curves for other hydrocarbon gases can be used the same way.

## MANUFACTURE AND DISTRIBUTION

A typical atmosphere-gas converter is shown in Fig. 24 and its flow diagram in Fig. 26. As indicated at the left in the flow diagram, fuel gas and air are drawn through visual flowmeters into a gas-combustion controller consisting of a proportioning mixer which regulates and controls the input air-gas ratio, and a motor-driven compressor. The gas-air-mixture line leaving the compressor leads to a volume-control valve, an automatic fire check, and a burner with refractory screen. The burner fits into the end of the combustion chamber, which is partially lined with insulating refractory brick and is water-jacketed. This chamber is filled with a bed of special catalyst brick, Fig. 27, which assists the reactions in proceeding to completion.

**Fig. 27.** Typical catalyst bricks used to fill combustion chambers of atmosphere-gas converters to assure complete reactions

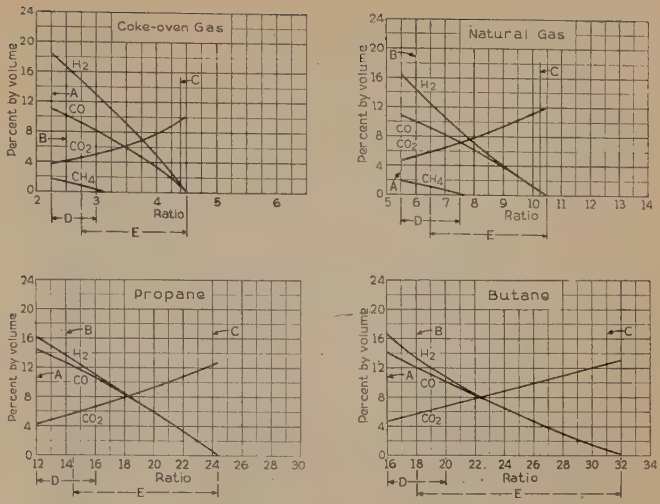

**Fig. 28.** Gas from atmosphere-gas converter is largely nitrogen. Curves show remaining constituents for various input air-gas ratios

*A:* Reducing mixture for furnace brazing and scale-free hardening—inflammable
*B:* Reducing mixture for bright annealing or normalizing steel—inflammable
*C:* Inert mixture for bright-annealing copper—not inflammable
*D:* Range of low-ratio-type machine
*E:* Range of high-ratio-type machine

While leaving the combustion chamber, the gas passes through a straight-tube surface cooler which partially condenses out the water vapor. This cooler is equipped with a removable bundle of corrosion-resisting brass tubes. The cooled gas and condensate then enter a velocity-type water separator, and the condensate drips into a drain from a trap. The processed gas leaves the separator, ready for use as protective atmosphere in the furnace or other equipment, unless some form of purification is necessary. In any event, for applications requiring constant flow, such as furnaces, the gas generally is piped directly from the converter or purifier without being subjected to intermediate storage. However, for applications where usage of the gas is intermittent, as in the paint industry, it has been found convenient to compress the gas into storage tanks at 50- to 150-lb pressure, and draw it off as needed. Details of this system will be described in a later part.

Performance of the atmosphere-gas converters with respect to changes in the input air-gas ratio when burning coke-oven or natural gas, propane, or butane is best indicated by the output-gas analysis charts in Fig. 28, which shows one chart for each type of fuel gas. It will be noticed that the characteristics applying to the different gases are about the same, but there are minor differences. The range of the low-ratio machines is indicated by the span *D*, and the high-ratio machines *E*. Curves show the various individual constituents in the combusted-gas with the exception of nitrogen, which is the largest single constituent and makes up the remainder not indicated by the curves. Mixtures most commonly employed for various applications are indicated in the caption. Other mixtures not so identified are also commonly employed for various uses.

## OTHER GASES

There are other mixed gases sometimes used as protective atmospheres for preventing oxidation, but which are more commonly employed for preventing both oxidation and decarburization. Because they fall more naturally into the latter classification, they will be presented in a later part. For example, combusted gas with its carbon dioxide and water vapor completely removed (neutralene), commonly used on medium- and high-carbon steels to prevent decarburization, is also employed for the bright-annealing of low-carbon steel tinplate stock, because the tin wets and flows on it more uniformly, thus giving a better-appearing product.

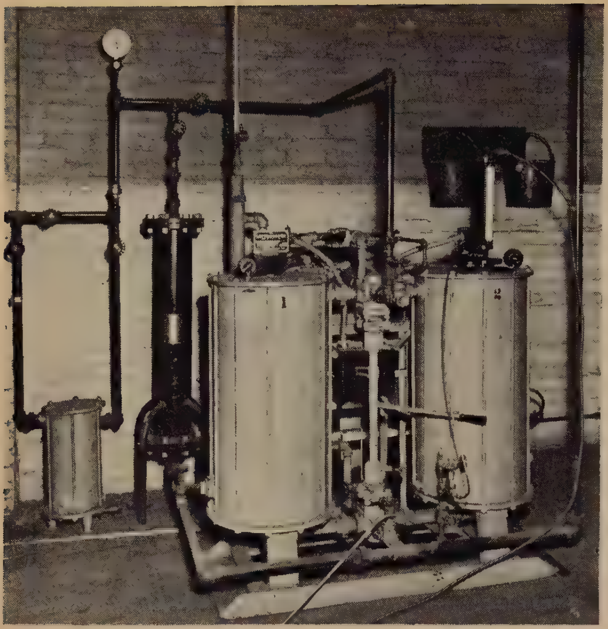

Fig. 29. Palladium catalyst purifier (*black tower, left center*) for converting oxygen with hydrogen into water vapor, and dual-chamber regenerative-type dryer (*right center*) for removing water vapor

## Purification of Gases

### OXYGEN REMOVAL

Sometimes hydrogen contains enough oxygen to be troublesome and purification is necessary. There are two well-known methods for removing oxygen from hydrogen, the more recent and the one considered best is to pass the hydrogen through a palladium catalyst purifier, Fig. 29 (black tower—left center), which converts oxygen with hydrogen into water. The unit operates at room temperature and is very effective; it is claimed that the unit removes oxygen to less than one part oxygen per million parts hydrogen. Hydrogen delivered from this purifier contains water vapor, of course; and, if dry gas is necessary, moisture removal is also required. Since the palladium catalyst can be poisoned by oil, it is customary to install an oil filter in the hydrogen line to remove any oil passed by the compressors.

The other method of oxygen removal from hydrogen is to pass the hydrogen over copper heated to about 1100 to 1200 F. The copper serves as a catalyst to convert the $O_2$ with $H_2$ into $H_2O$, removing $O_2$ except for traces. The hydrogen can then be further purified by passing it over hot ferro-manganese, ferro-titanium, or ferro-silicon at 1650 to 1850 F. The copper chips are contained in tubes or retorts, and usually are heated externally by electric heating.

To remove oxygen from nitrogen, a small amount of hydrogen is added to the nitrogen, and the mixture is passed over palladium catalyst so that the $H_2$ and $O_2$ can combine to form $H_2O$. Another method is to pass the nitrogen over hot copper, which oxidizes the copper and, in so doing, removes the oxygen from the nitrogen. For this method, the copper oxide must be reduced back to copper for further effectiveness.

### MOISTURE REMOVAL

The effect of water vapor in a furnace atmosphere was given in Part II along with Equations (11) and (12) and Fig. 5. Sometimes moisture must be either partially or completely removed to obtain satisfactory results. Partial removal can be accomplished by refrigeration or adsorption in regenerative-type driers. Complete moisture removal is usually done in a regenerative-type unit.

Fig. 30 shows in graphic form dew point and moisture content of gases and the extent of moisture removal by various methods. Table VII gives the same dew point and percentage-moisture-content data, but also includes moisture-weight data. Fig. 30 indicates that the bulk of the moisture can be removed by refrigeration to 40 F. For example, from a dew point of 70 F and

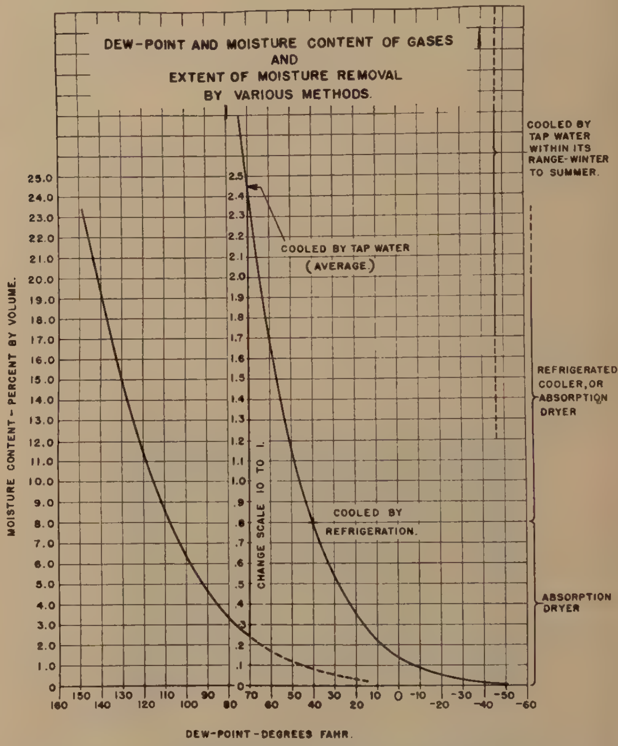

Fig. 30. Moisture content of gases at various dew points, and extent of moisture removal by cooling with tap water and refrigeration and by use of regenerative-type or absorption dryer

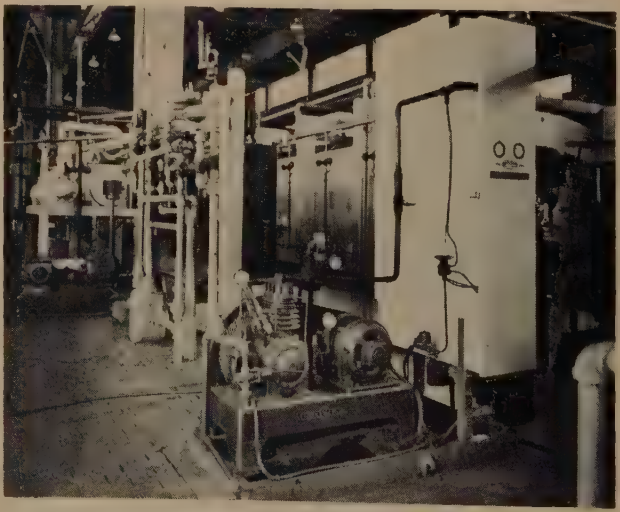

Fig. 31. Refrigerated-gas cooler (*right center*) rated 6000 cfh, consisting of condensing unit and insulated finned-tube evaporator

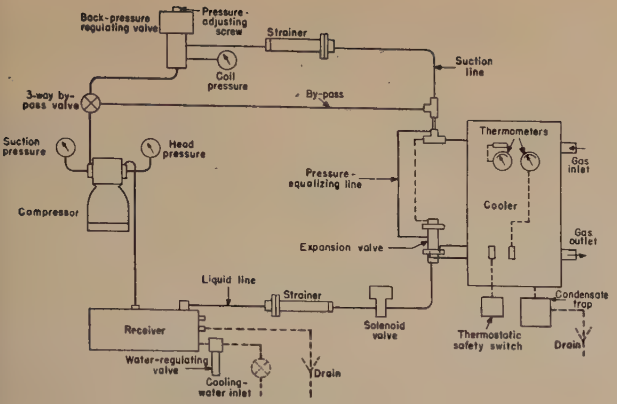

Fig. 32. Typical flow diagram of refrigerated-gas cooler

moisture content of 2.47 percent, refrigeration will reduce the dew point to about 40 F, with a moisture content of 0.8 percent. Thus, 67 percent of the moisture is removed in this one step; with a higher initial dew point and the same end dew point, the ratio would be greater.

### REFRIGERATED GAS COOLER

A typical refrigerated gas cooler and its flow diagram are shown in Figs. 31 and 32. The equipment consists of a condensing unit (*left*), and an insulated finned-tube evaporator (*right*), with water separator and condensate trap mounted on a common base. Freon refrigerant is used in the system.

## Table VII

## TABLE SHOWING RELATION BETWEEN DEW-POINT AND MOISTURE CONTENT OF GASES

**With a known dew-point temperature, which is indicated by a dew-point indicator or recorder, the moisture content can be read directly from the table.**

**The table shows the amount of water vapor in air or other gas at various dew-point temperatures, and at a pressure of one atmosphere (14.7 psi)**

| Dew-point Temp F | MOISTURE CONTENT | | |
|---|---|---|---|
| | Lb per 1000 Cu Ft | Milligrams per Liter | * Per Cent by Volume |
| 110 | 3.77 | 60.5 | 8.70 |
| 108 | 3.57 | 57.0 | 8.20 |
| 106 | 3.38 | 54.0 | 7.75 |
| 104 | 3.20 | 51.0 | 7.30 |
| 102 | 3.02 | 48.5 | 6.40 |
| 100 | 2.86 | 45.6 | 6.45 |
| 98 | 2.70 | 43.2 | 6.10 |
| 96 | 2.55 | 40.8 | 5.75 |
| 94 | 2.41 | 38.7 | 5.40 |
| 92 | 2.27 | 36.4 | 5.05 |
| 90 | 2.14 | 34.3 | 4.75 |
| 88 | 2.02 | 32.4 | 4.46 |
| 86 | 1.90 | 30.5 | 4.18 |
| 84 | 1.79 | 28.7 | 3.92 |
| 82 | 1.68 | 26.9 | 3.68 |
| 80 | 1.58 | 25.3 | 3.46 |
| 78 | 1.49 | 23.9 | 3.22 |
| 76 | 1.40 | 22.5 | 3.02 |
| 74 | 1.31 | 21.0 | 2.84 |
| 72 | 1.23 | 19.7 | 2.65 |
| 70 | 1.15 | 18.4 | 2.47 |
| 68 | 1.08 | 17.3 | 2.31 |
| 66 | 1.01 | 16.2 | 2.16 |
| 64 | 0.95 | 15.2 | 2.02 |
| 62 | .89 | 14.2 | 1.88 |
| 60 | .83 | 13.3 | 1.75 |
| 58 | .777 | 12.5 | 1.63 |
| 56 | .725 | 11.6 | 1.51 |
| 54 | .677 | 10.9 | 1.40 |
| 52 | .632 | 10.1 | 1.30 |
| 50 | .589 | 9.5 | 1.21 |
| 48 | .549 | 8.81 | 1.12 |
| 46 | .511 | 8.20 | 1.04 |
| 44 | .475 | 7.62 | 0.966 |
| 42 | .442 | 7.08 | .894 |
| 40 | .410 | 6.58 | .827 |
| 38 | .381 | 6.12 | .765 |
| 36 | .354 | 5.68 | .707 |
| 34 | .328 | 5.26 | .653 |
| 32 | .304 | 4.88 | .602 |
| 30 | .280 | 4.50 | .553 |
| 28 | .259 | 4.15 | .511 |
| 26 | .240 | 3.84 | .472 |
| 24 | .221 | 3.55 | .434 |
| 22 | .204 | 3.28 | .398 |
| 20 | .189 | 3.02 | .367 |
| 18 | .174 | 2.79 | .337 |
| 16 | 0.160 | 2.56 | 0.308 |
| 14 | .147 | 2.35 | .282 |
| 12 | .135 | 2.16 | .258 |
| 10 | .124 | 1.99 | .236 |
| 8 | .114 | 1.83 | .216 |
| 6 | .105 | 1.68 | .198 |
| 4 | .096 | 1.54 | .180 |
| 2 | .088 | 1.41 | .165 |
| 0 | .081 | 1.30 | .150 |
| −2 | .074 | 1.18 | .136 |
| −4 | .0671 | 1.08 | .124 |
| −6 | .0612 | 0.982 | .113 |
| −8 | .0558 | .896 | .102 |
| −10 | .0508 | .815 | .093 |
| −12 | .0462 | .742 | .084 |
| −14 | .0420 | .674 | .076 |
| −16 | .0381 | .610 | .0685 |
| −18 | .0346 | .555 | .0619 |
| −20 | .0314 | .505 | .0558 |
| −22 | .0284 | .455 | .0503 |
| −24 | .0257 | .410 | .0452 |
| −26 | .0232 | .372 | .0407 |
| −28 | .0209 | .336 | .0364 |
| −30 | .0189 | .303 | .0328 |
| −32 | .0170 | .272 | .0294 |
| −34 | .0153 | .245 | .0264 |
| −36 | .0137 | .220 | .0235 |
| −38 | .0123 | .197 | .0210 |
| −40 | .0110 | .177 | .0188 |
| −42 | .0098 | .157 | .0167 |
| −44 | .0088 | .141 | .0149 |
| −46 | .0079 | .127 | .0132 |
| −48 | .0070 | .112 | .0117 |
| −50 | .0063 | .101 | .0104 |
| −52 | .0056 | .090 | .0092 |
| −54 | .0050 | .080 | .0082 |
| −56 | .0044 | .071 | .0072 |
| −58 | .0039 | .063 | .0063 |
| −60 | .0034 | .054 | .0056 |
| −65 | .0025 | .040 | .0041 |
| −70 | .0018 | .029 | .0029 |
| −75 | .0013 | .021 | .0021 |
| −80 | .0009 | .014 | .0015 |
| −85 | .0007 | .011 | .0010 |
| −90 | .0005 | .008 | .0007 |
| −95 | .0003 | .005 | .0005 |
| −100 | .0002 | .003 | .0003 |

*Vapor pressures in atmospheres at various dew-point temperatures can be obtained by dividing the values for "per cent by volume," given in this table, by 100.

### REGENERATIVE-TYPE DRYER

A typical regenerative-type dryer is shown in Fig. 29 and its flow diagram in Fig. 33. Such units are able to reduce the dew point of gases to as low as −100 F. For rates of flow up to 1000 cfh, it is customary to use such a drying unit for complete moisture removal; but for flows from 1000 cfh upward, it is rather common to use a combination of a refrigerated gas cooler and the regenerative-type dryer for the sake of economy in both initial and operating cost. The dryer shown consists of two towers with suitable valving arrangement, blower, and heating units. While the gas is passing through the drying chamber at the left, the other chamber at the right is reactivated by means of electric heat, with the blower operating to drive the moisture out into the room. After three or four hours of heating, the chamber is then cooled either by room air or circulating water. The complete reactivating period takes about 8 to 10 hr, at the end of which time the gas flow is normally circulated through the reactivated tower, heat is applied to the other moisture-laden tower, and the cycle is repeated. The drying towers are normally filled with activated alumina or silica gel.

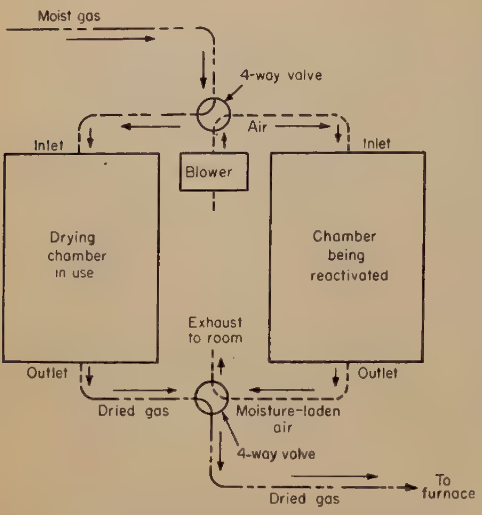

Fig. 33. Typical flow diagram of regenerative-type dryer

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### AMMONIA REMOVAL

Dissociated ammonia usually contains less than 0.05 percent ammonia, which generally is not troublesome. However, this ammonia can be removed by use of a regenerative-type dryer, the same as that described for moisture removal.

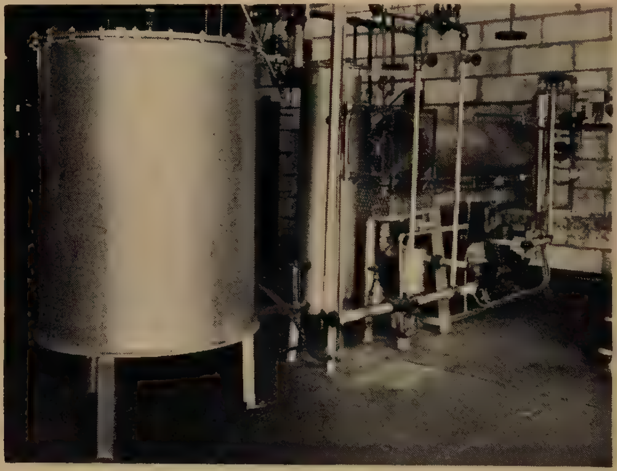

Fig. 34. Sulfur removal equipment consisting of iron-oxide tower (*left*) and water-spray tower (*center*), with atmosphere-gas converter (*right*) supplying protective atmosphere for bright-annealing copper wire

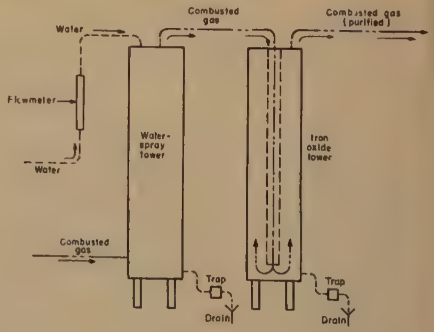

Fig. 35. Typical flow diagram of sulfur-removal equipment

### SULFUR REMOVAL

A typical sulfur removal equipment is shown in Fig. 34 and its flow diagram is in Fig. 35. The combusted gas first passes through a water-spray tower which removes the sulfur dioxide ($SO_2$). Then it passes through a tower containing iron oxide on wood shavings called "lux," which removes hydrogen sulfide ($H_2S$). Thus, the gas usually leaves the equipment completely free from sulfur compounds. The sulfur removers require practically no attention, and are therefore convenient to operate.

(*To be continued*)

# FACTORY-ASSEMBLED SUBSTATIONS: Part II

## Consideration of types of voltage regulation for factory-built units and the application of package substations to industrial use

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Unit Equipment Division, Central Station Divisions
General Electric Company

REGULATION of feeder voltage in standard, factory-built substations can be accomplished either by automatic load-ratio control equipment in the transformer or by a separate voltage regulator on each feeder.

### METHODS OF VOLTAGE REGULATION

There are four general methods of regulation. These are:

(1). Bus regulation (FIG. 7)
(2). Group feeder regulation (FIG. 8)
(3). Individual feeder regulation (FIGS. 9, 10, 11)
(4). Individual phase regulation (FIG. 12)

These methods are illustrated schematically in FIGS. 7 through 12 and they will be described in the order of increasing cost and generally increasing quality of voltage regulation maintained.

### *Bus Regulation*

In addition to the primary-network applications, where bus regulation is a natural, this method is usually acceptable also for a simple radial substation as shown in FIG. 7, where kva ratings are comparatively small. This is accomplished by the automatic load-ratio-control equipment in the transformer. This under-load tap-changing equipment provides adjustment of the secondary voltage of the transformer over a range of 20 percent in ⅝-percent steps to compensate for variations in the supply voltage and for line drop in the secondary lines at various loads.

Bus regulation in such radial substations requires that all feeders be of about the same length and have loads and peaks which coincide. If these conditions are not met, a compromise in the voltage maintained on each feeder must be made. These compromises are not objectionable on the types of loads usually supplied by the relatively small substations of the radial type, although the use of bus regulation for larger stations should be more critically examined as the obvious saving in substation costs may unsuspectingly be more than overbalanced by additional costs required in the distribution systems to keep voltage within acceptable limits.

### *Group Feeder Regulation*

As the size of the substation and the number of feeders increases, however, the acceptability of bus regulation decreases. One improvement is group feeder regulation as shown in FIG. 8. In this case, those feeders with similar characteristics with regard to length and load are grouped on one bus section and those of other similar characteristic on another. This obviously permits regulation more nearly matching that required on each feeder than would be possible if all feeders were on a single regulated bus. The feeders from a substation may be grouped on any number of buses as required by substation size and feeder characteristics. FIG. 8 shows the circuit diagram of a substation with feeders grouped on three buses.

With this arrangement, if one transformer is out of service for maintenance or other reasons, the load on the bus associated with that transformer is carried by the remaining unit or units. When this transfer is made, it is necessary to prevent overcompensation by the transformer which is carrying this new load. Overcompensation causes that transformer to hold a bus voltage which is higher than necessary. This overcompensation is prevented by paralleling the compensators on the transformers through normally-open auxiliary contacts on the bus tie breaker. When this breaker is closed to connect both bus sections to one transformer, the compensators are paralleled and each unit sees only about half of its new load, which is about its normal load. Under these emergency conditions, the voltage held is a further compromise with that desired but is usually acceptable in view of the short duration of these conditions.

### *Individual Feeder Regulation*

Regulation of voltage on each individual feeder permits an excellent degree of voltage control since the requirements of that feeder only need be considered. Regulation of each feeder individually may be accomplished in any one of three ways:

(1). Single feeder units
(2). Duplex substation
(3). Regulator-reactor-transfer bus unit

Each of these methods will be described in the following paragraphs.

---

This article is so paged that without mutilating other articles, it can be readily removed for filing as a group of full-size consecutive pages.—EDITOR

*Single Feeder Units.* A further refinement of the problem of supplying regulated voltage is to apply a single transformer with automatic load-ratio control for each feeder. This arrangement is shown in FIG. 9 and accomplishes the same individual feeder regulation that is provided by individual feeder regulators.

As shown in FIG. 9, when an individual transformer is used for each feeder, a transfer bus with a spare transformer unit is required to provide standby and transfer facilities. The transfer bus is metal-enclosed in the same fashion as the circuit-breaker equipment, but must be cable-connected to the substation feeder units.

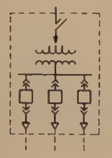
Fig.7

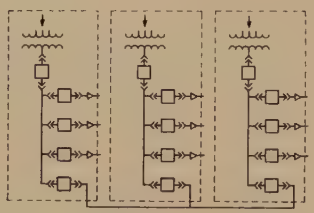
Fig.8

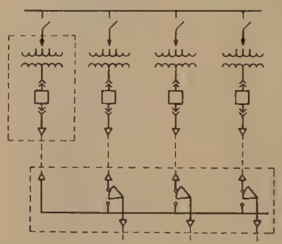
Fig.9

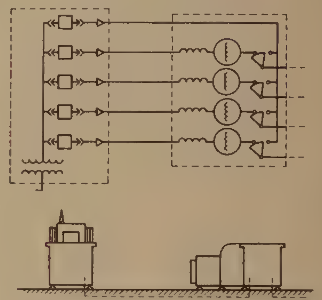
Fig.12

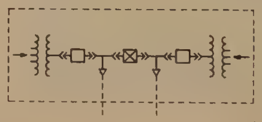
Fig.10

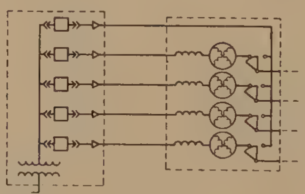
Fig.11

**Figs. 7-12. Type of feeder voltage regulation**

Fig. 7. Bus regulation

Fig. 8. Group feeder regulation

Fig. 9. Single feeder units

Fig. 10. Duplex unit

Fig. 11. Regulator-reactor-transfer bus unit

Fig. 12. Individual phase regulation

*Duplex Substations.* In those locations where a feeder outage necessitating manual switching cannot be accepted, a single feeder substation may not be acceptable, since there is no source which will automatically pick up the load in case of trouble. This objection may be overcome, and also a more economical arrangement may result, by the use of the duplex substation as shown in FIG. 10. Each of the two transformers normally supplies an individual feeder. The two feeders are connected together automatically in case of the loss of voltage on either transformer. In normal operation, all of the advantages of a single regulated source for each feeder exist, plus the additional advantage of having a second source available in cases of emergency or for maintenance on one half of the substation. On transfer, the auxiliary contacts on the tie breaker parallel the compensators on the two transformers to prevent overcompensation by the unit remaining in service under the new conditions.

The duplex substation often provides the lowest-cost arrangement for providing individual feeder regulation in those cases where multiple-source supply and the equivalent of transfer-bus facilities are desired.

*Regulation-Reactor-Transfer Bus Unit.* Another method of providing individual feeder regulation is the use of standard factory-assembled units arranged in the manner shown in FIG. 11. By combining three individual feeder regulators with a metal-enclosed transfer bus, by-pass facilities are provided not only for maintenance of the regulator, but also for the feeder breaker. For those conditions where short-circuit duties exceed 25 times the rating of the regulator, current-limiting reactors may be throat-connected to the regulators and transfer bus to limit short-circuit current to the regulator short-circuit rating.

## *Individual Phase Regulation*

There is a further refinement that can be used in the application of individual regulators to substation feeders, namely, single-phase control to permit control of voltage on each phase individually. This type of control is sometimes necessary on systems where the loads are predominately single-phase or where the "phase-area" system of distribution is used. It is accomplished by the same physical arrangement as that shown for the regulator-reactor-transfer bus for three-phase regulation. The three single-phase regulators in a single tank are each equipped with their own drives and controls. This arrangement can be connected to reactors and transfer bus as required. The diagram for this type of control is shown in FIG. 12. With the trend toward more and more three-phase loads the use of "phase-area" distribution, and consequently the need for this type of substation, is diminishing.

### PACKAGE SUBSTATIONS: INDUSTRIAL APPLICATION

Small- and medium-sized industrial plants are usually supplied with power at some voltage below 15 kv. This means that the high-voltage circuits can be carried directly into the plant to the secondary substations close to the load centers. On the other hand, most large plants and some smaller ones must necessarily be supplied at some higher voltage, such as 33 or 66 kv. In these cases the necessary transforming and switching equipment to reduce the voltage to a level that can be carried into the plant must be provided by either the industrial plant itself or the electrical utility serving it.

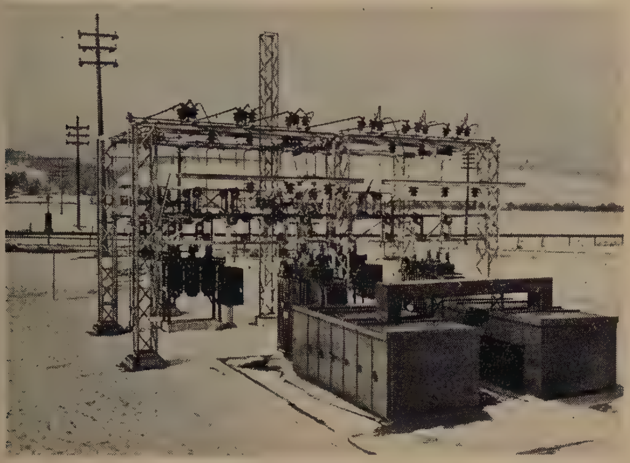

Fig. 13. Typical package substation serving an industrial plant

Standardized factory-assembled package substations are particularly adaptable to industrial plants because they provide all the necessary high-voltage switching, transforming equipment, and low-voltage circuit protection in a simple, complete, economical package. A typical package substation serving an industrial plant is shown in FIG. 13. The high-voltage ratings may be any voltage from 22 kv up to 132 kv whereas the outgoing voltage is usually 2.4, 4.16, or 13.8 kv. In modern installations, 4.16 kv is usually preferred over 2.4 kv whereas the choice between 4.16 and 13.8 kv depends mainly upon the expected size of the plant, 4.16 kv being used in plants with loads up to 7500 kva and 13.8 kv in plants of larger size.

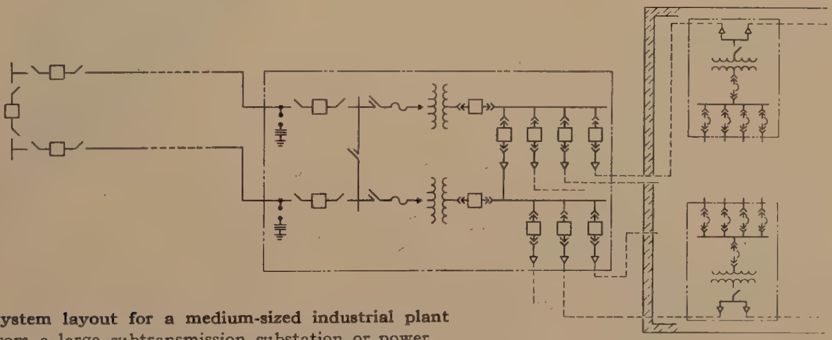

**Fig. 14. Typical system layout for a medium-sized industrial plant**
Power supplied from a large subtransmission substation or power plant is fed through the two bus circuits shown at the left, and by intervening overhead subtransmission circuits, to the primary substation from which it is distributed through 4.16- or 13.8-kv feeders to the secondary substations at right

Industrial plants use three of the five standardized types of primary substations. These are the radial, the low-voltage selective, and the spot network. The choice depends upon the load and the service continuity required. Any of the three types of systems may be used, depending upon what is available and the need for reliability.

The radial substation (FIG. 2a)* is usually used by smaller plants that do not require too high a degree of service continuity. Typical sizes are 750 to 3000 kva. The low-voltage selective substation (FIG. 2f) is the most common type for medium- and large-size industrial plants. It may consist of two units placed side by side as in FIG. 13 or three units as shown in FIG. 5b. Typical standard ratings of this equipment range from 2000 kva to 45,000 kva.

The bus-tie circuit breakers are operated normally open to reduce interrupting duty and to simplify operation. In event of transformer outage due to trouble or maintenance the necessary tie breakers are closed to serve all feeders from the remaining transformer. There is necessarily a slight interruption to one half or one third of the feeders in the case of automatic throw-over operation during a fault. The spot-network substation (FIG. 2e) is used by industrial plants in those cases where even a momentary service interruption such as occurs with the low-voltage selective arrangement cannot be tolerated. Many continuous-process operations in the petroleum and metal-reduction industries require this kind of continuity of service. Naturally, the relaying and over-all operation with this type of substation is more complex than with the low-voltage selective arrangement. Typical ratings range from 2000 kva to 20,000 kva.

Regardless of the type of substation chosen, the general pattern of circuits from the substation follows that indicated by FIG. 14. In other words, two to a dozen circuits go into the industrial plant to feed secondary substations. One or more circuits serve large motor control centers at 4.16 kv or 2.4 kv. Usually one circuit serves outlying loads around the plant area.

*(To be continued)*

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*Figs. 1-6 inclusive appeared in Part I, in the February 1949 issue.—Ed.

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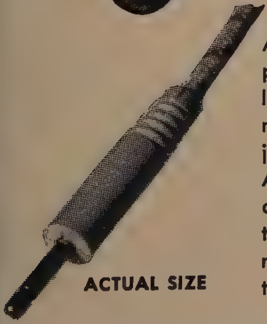

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# VIBRATION INSTRUMENT FOR GAS TURBINES

**The problems encountered with higher speeds than those of steam turbines, special mountings, and combustion-pulsation effects required the development of a special instrument for measuring only vibrations associated with once-per-revolution unbalance**

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PROBLEMS of vibration in the operation of aircraft gas turbines differ in many respects from those encountered in the operation of conventional steam turbines. These differences are due to various effects, such as the higher speeds of gas turbines, their mounting, and the combustion-pulsation effect of the combustion chamber. For these reasons, a special instrument was designed and developed for vibration measurements on these turbines. Characteristics of this instrument are such that only those vibrations associated with the once-per-revolution unbalance are measured; other vibrational qualities, not needed for operational purposes, are rejected.

### LIMITATIONS OF GENERAL-PURPOSE INSTRUMENTS

During the latter part of 1944, production testing of the TG-180 gas turbine was in progress in the General Electric Company's Schenectady Works. As in testing any other high-speed rotating equipment, the vibration at running frequency had to be watched carefully. Since an increase in vibration of this frequency indicates development of internal trouble, such as compressor blades or turbine-bucket breakage, adequate and reliable vibration-measuring equipment was needed. Wide-range general-purpose vibration instruments were available and their use was attempted. It soon became apparent, however, that this type of instrument would not be satisfactory when applied to gas-turbine testing.

The quantity most important to measure was the vibration displacement caused by the once-per-revolution unbalance of the turbine and compressor rotor over a range from idling to full speed. Displacement at the running frequency was considerably smaller than the low-frequency vibrational displacement of the turbine mounts. This low-frequency component was of no significance to the operational tests and was superposed on the once-per-revolution unbalance; hence, the general-purpose vibration instruments, which were designed to cover a wide frequency range, measured both vibrations.

Because the vibration displacement of the low frequency is far greater than the running-frequency vibration, it masked out the latter and the indications were thus erroneous. It was quite common to read 30 mils or more vibration displacement with these instruments when it was known with a fair degree of certainty that the vibration due to the once-per-revolution unbalance was only about three mils.

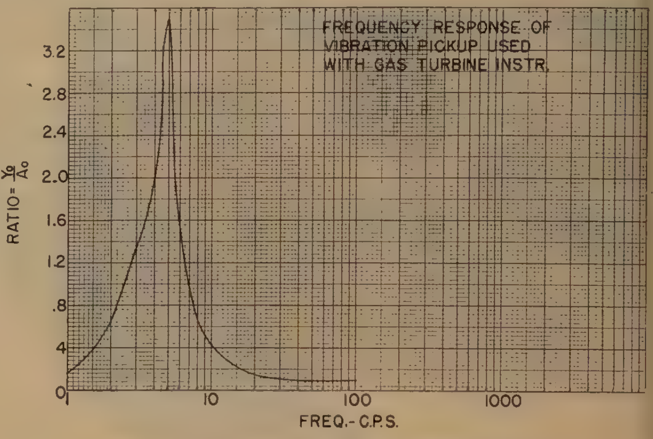


Fig. 1. Characteristic curve of the vibration detector

Recognizing this unsatisfactory condition, engineers in charge of the tests attempted to surmount the difficulty by using electric filters. It was thought that if a filter could be designed with characteristics that would attenuate all the low-frequency vibrations and pass only the once-per-revolution unbalance frequencies, the general-purpose instruments could still be used.

Several filters were designed and tried, but it was found that all of them decreased the sensitivity of the vibration instrument to such a degree that it was no longer useful unless further amplification was inserted to regain the lost sensitivity. Furthermore, it was impossible to eliminate all of the undesired low-frequency component. It therefore was decided to abandon that approach to the problem and to develop a new vibration instrument to fit the need in this particular field.

### REQUIREMENTS FOR VIBRATION MEASUREMENTS

Before a set of specifications could be drawn up for the new instrument, it was deemed advisable to investigate thoroughly the vibrations present in the urbines. So a program was laid out involving the ollowing major items:

(1). Set up special vibration-measuring equipment to obtain oscillograms of vibration displacement on several types of gas turbines at different speeds, and analyze the records

(2). Find the natural, or resonant, frequency of the turbine mounting or that of any other structure below 30 cycles per second

(3). Find the maximum temperature to which the vibration detectors would be subjected at the various measuring points

(4). Co-ordinate the foregoing information with the known natural frequency of the vibration detectors being used

Analysis of the oscillograms showed the presence of a low-frequency large-displacement component of vibration, due primarily to the movement of the turbine in its mount. The frequency of this component was about six cycles per second, and it was found to have a magnitude in the order of 30 mils, while the displacement due to the unbalance was approximately three mils. The ratio of the size of the undesired signal (that due to the turbine's movement in its mount) to the desired signal was made still greater by the resonant frequency of the seismic mount of the detector. This further obscured the sought-for readings. A characteristic curve of the detector is shown in Fig. 1.

The maximum temperature to which the detectors are to be subjected was found to be about 300 F. While the detectors used would withstand this temperature, special attention would have to be paid to the oil used in damping, because of its low viscosity at such temperatures.

### SPECIFICATIONS FOR NEW INSTRUMENT

After this information had been obtained, specifications were drawn up for the development of the new vibration instrument. Briefly, these specified that the instrument should:

(1). Include an electronic amplifier having a flat response within ± 1 db, over a frequency range of 30 to 300 cycles

(2). Be portable, have dimensions of approximately 12 × 7½ × 10 in., and weigh less than 20 lb

(3). Be designed for operation with a velocity-type vibration detector having a sensitivity of approximately 0.1 millivolt per mil per second

(4). Be capable of measuring displacement, velocity, and acceleration

(5). Have sensitivity sufficient that one-mil vibration displacement will give full-scale reading

(6). Include enough multiplier taps to make possible the reading of higher vibrations

(7). Operate from a 110-115-volt 50-60-cycle external source of power

(8). Cut off sharply below 30 cycles per second; at 20 cycles 3.5 db low, at 10 cycles 14 db low, and at 7 cycles 29.5 db low.

### PICKUP, AMPLIFIER, AND FILTERS

The vibration instrument, as developed, consists of a velocity-type pickup, the output of which is fed to an electronic amplifier and thence to an indicating instrument calibrated in terms of vibration quantities. The most important feature in the design of the amplifier is the inclusion of filters to eliminate the low-frequency component of vibration. The filters are of the capacity-resistance infinite-rejection type. To make sure that none of the six-cycle vibration would pass through, two separate filters were designed—one to reject at 2½ cycles and the other at six cycles per second. Curves of these two filters are shown individually in Fig. 2. In Fig. 2a is a curve made of the combination of the two. Fig. 3 shows the over-all frequency response of the vibration amplifier.

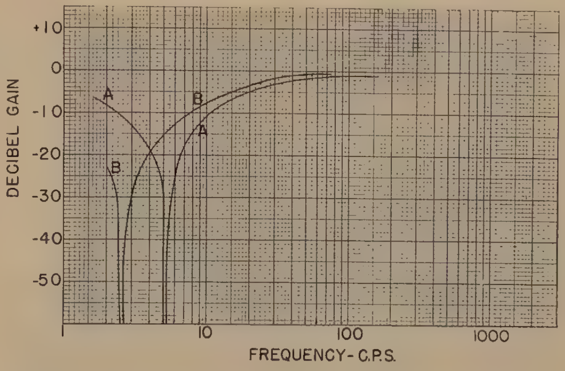


Fig. 2. Characteristic curves of the two filters included in the electronic amplifier to reject vibrations
A: 6 cycles per second B: 2½ cycles per second

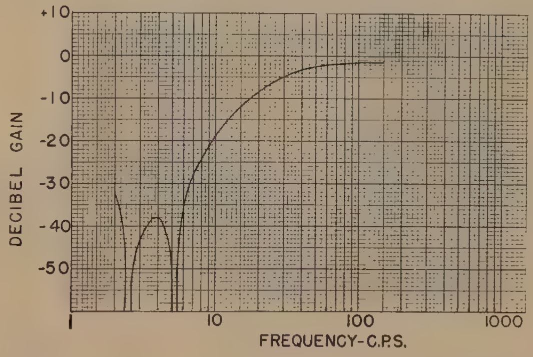


Fig. 2a. Combination of the two curves shown in Fig. 2

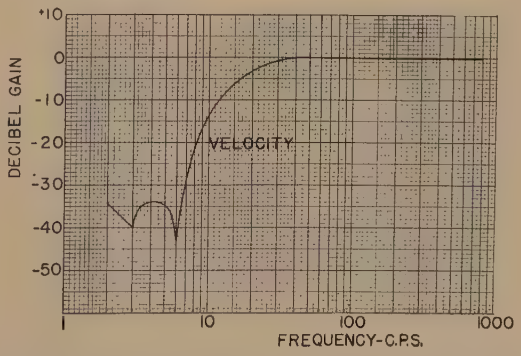
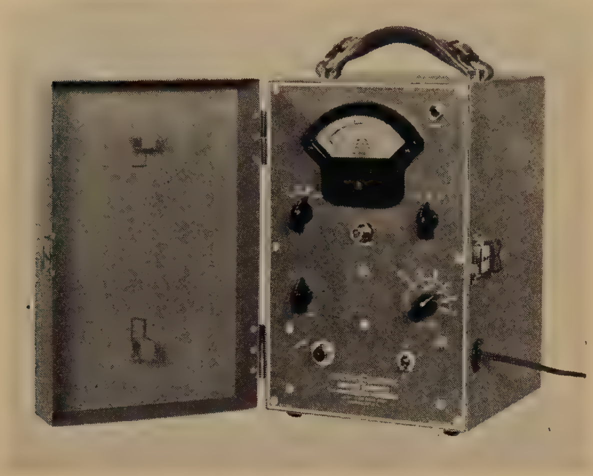


Fig. 3. Over-all frequency-response curve of the vibration amplifier

Because the outputs of filters of this particular type should terminate in an open circuit, cascading them was not advisable for best operation. Consequently, one of the filters was inserted ahead of the grid of the first-stage tube and the second filter was inserted between the first plate and second grid of a 6SN7 tube.

### INSTRUMENT RANGE

The over-all full-scale sensitivity of the instrument is one mil full scale for displacement, 0.1 in. per second velocity, and 0.1g acceleration. Provision is made for changing the full-scale sensitivity to increase the measurement range. Table I gives the available ranges.



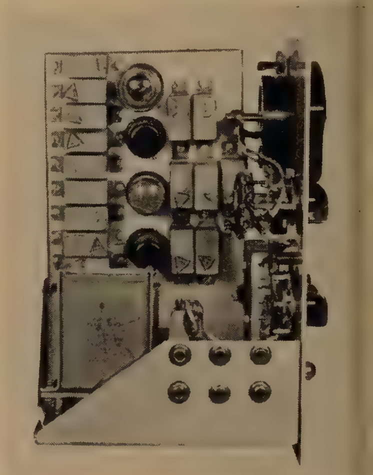


**Fig. 4.** The vibration-indicating instrument *(left)* with cover open and *(right)* removed from the case

TABLE I
AVAILABLE RANGES OF FULL-SCALE SENSITIVITY OF VIBRATION INSTRUMENT

| Acceleration (g) | Velocity (In. per sec) | Displacement (Mils) |
|---|---|---|
| 0.1 | 0.1 | 1 |
| 0.3 | 0.3 | 3 |
| 1 | 1 | 10 |
| 3 | 3 | 30 |
| 10 | 10 | 100 |
| 30 | 30 | 300 |
| 100 | 100 | 1000* |
| 300 | 300 | 3000* |

* These scales are available but may never be used because of limitation of the detector to high accelerations and displacements.

Through use of a selector switch it is possible for as many as five vibration detectors to be connected to the instrument, and measurements to be taken with any one. An output receptacle is provided so that the amplified signal from the detectors can be observed on a cathode-ray oscilloscope, listened to through earphones, recorded, or indicated on a remote switchboard-type instrument. By the use of a magnetic oscillograph and a proper impedance-matching transformer, oscillograms also can be taken. When this output receptacle is used, the indicating instrument on the panel automatically becomes inoperative.

### USE ON OTHER GAS TURBINES

It became desirable to use this instrument also for the measurement of vibration on the TG-100 gas turbine, which differs from the TG-180 in that a propeller is provided in addition to the jet for propulsion. It was therefore necessary to check the vibration of the propeller, from near-idling speed to full speed, as well as that of the turbine unit. The propeller running speed is considerably lower than the lowest measurable frequency of the newly developed vibration instrument. In order to adapt the instrument to measure vibrations at this low frequency, a special circuit was designed for insertion between the vibration detector and the input to the vibration instrument so that the low-frequency cutoff of the amplifier could be extended from 30 to 12 cycles per second.

**Fig. 5.** The vibration-indicating instrument in use

Briefly, this special circuit was primarily a resonant circuit, so designed as to boost the low-frequency response of the amplifier to obtain a relatively flat over-all response from 12 to 20 cycles per second, which was the range over which the propeller vibration was to be measured. The circuit decreased the over-all sensitivity. At low frequencies, however, a larger vibration displacement is permissible; hence, this decrease in sensitivity does not impair the operation appreciably. Calibration curves are used with the special circuit, called the low-frequency range extender.

To measure the vibration of the TG-100 turbine, a special filter was designed for insertion between the vibration detector and the input to the amplifier, to be used over a frequency range of 120 to 300 cycles per second. This filter, known as a band-pass filter, also has a calibration curve for use when testing this type of turbine.

To maintain the calibration of the instrument in the field, a one-point calibration check was built into the instrument. This should be used before measurements are taken, at least once during the taking of readings, and at the end of the test.

Table II lists some of the types of gas turbines for which this vibration instrument is used and the speed ranges over which the vibration is measured.

TABLE II
TYPES OF GAS TURBINES FOR WHICH THE VIBRATION INSTRUMENT IS DESIGNED

| Type | Idling Speed | Maximum Speed | Measuring Range | |
|---|---|---|---|---|
| | | | Freq. Rpm | Displ. Mils |
| I-16 | 5000 | 17,000 | 7500-17,000 | 0.2-4 |
| I-40 | 3500 | 12,000 | 8000-12,000 | 0.2-4 |
| TG-100 | | | 720-1200 | 0.5-50 |
| | | | 7800-13,200 | 0.5-10 |
| TG-180 | | | 1800-8000 | 0.2-30 |
| TG-190 | | | 2000-8000 | 0.5-15 |

FIG. 4 is an illustration of the vibration instrument in its present form. In FIG. 5 the instrument is shown in use, and in FIG. 6 the vibration detector is shown mounted on the turbine.

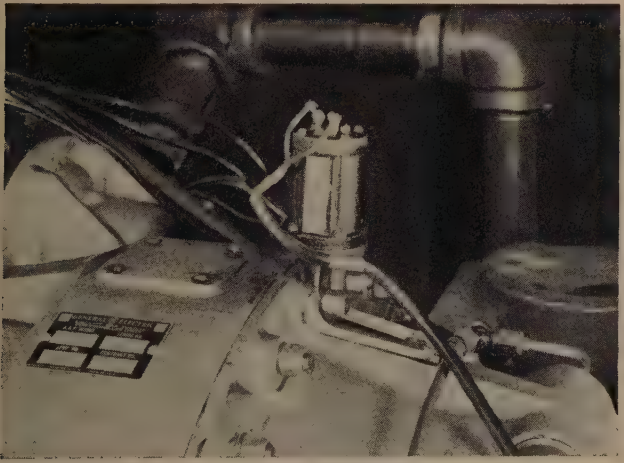


Fig. 6. The vibration detector in position on a gas turbine

The instrument is designed for use on a 110-115-volt 50-60-cycle power supply and ordinarily should be operated from that supply. But in certain applications in which the instrument has been used for flight tests this supply has not been available. In such instances a 60-cycle inverter, operating from the ship's d-c supply, has been used; in others, where the d-c supply was not available, the instrument has operated satisfactorily from the ship's 400-cycle supply. In the latter case the built-in calibration check had to be slightly modified.

These instruments have been used extensively in the production testing of gas turbines and have also been used in other vibration investigations, as well as in actual flight tests. It is expected that their applications will be extended as experience further demonstrates the value of their special design features for the measurement of vibration.

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# A TECHNIQUE FOR CALCULATING INDUCTANCE, REACTANCE, IMPEDANCE, AND SHEATH VOLTAGE OF SINGLE-CONDUCTOR CABLE IN DUCT BANKS

By F. H. BULLER
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THE calculation of the inductance of a group of single-conductor cables, while it tends to be a rather long-drawn-out operation, is theoretically quite simple; all that is necessary is to determine the self-inductance of each cable, and superpose the mutual effects due to each of the other cables.

If it is desired to take into account the uneven distribution of current in the individual conductors, due to the variations in internal reactance which produce skin effect and proximity effect, the calculation becomes very complicated.*

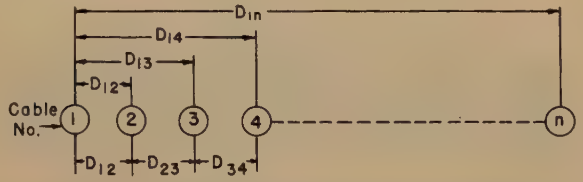

Fig. 1. Designations of spacing for cable arrangement side-by-side in ducts

Fortunately, those effects are secondary, and can usually be neglected, at least insofar as reactance and inductance are concerned at 60 cycles, with center-to-center spacings of the order of 5 to 6 inches, even where comparatively large conductors are involved. In general, these effects tend to reduce the reactance when conductors carrying current in opposite directions are placed close together, and to increase it when conductors carrying current in the same direction are placed close together. The effect on reactance is much less than the corresponding effect on effective a-c resistance (skin effect and proximity effect).

A number of authorities have published formulas for reactance of cables in groups, neglecting these effects. While these formulas are not inherently complicated, they tend to give tedious calculations when a group contains numerous cables.

The writer has found the reactance formula given later as Equation (2) to be the simplest to handle when a large number of cables are involved. While it appears to be somewhat more complicated than some other available formulas, it turns out to be simpler to use than many easier-looking formulas, if the proper technique is applied.

ASSUMPTIONS ON WHICH FORMULAS ARE BASED

Consider $n$ cables in a random arrangement. In FIG. 1, these cables are shown in a straight line, to simplify the visualization of the problem; actually, however, the following formulas apply equally well to a random arrangement.

The inductance $L$ of Cable No. 1 is defined as the flux linkages per ampere with this cable, produced by Cable 1 itself (self-inductance), and by all the other cables in the group (mutual inductance). To calculate this inductance, it is assumed

(1). That the current in Cable $k$ is $I_k$ (expressed as a vector)

(2). That $\sum_{1}^{n} I_k = 0$

(3). That distance from Cable $n$ to Cable $k$ is $D_{nk}$

(4). That radius of the conductor of Cable 1 is $r$

(5). That the current is uniformly distributed over the conductor. This means that current distortion of the type which produces skin effect and proximity effect is neglected. In practical calculations of reactance (*not* of a-c resistance) this assumption is usually justified, and gives a value slightly higher than the true one. Those who require greater accuracy for any reason, or who have to solve problems involving very large conductors in very close proximity, or involving high frequencies, are referred to the work of Prof. H. B. Dwight.(1)

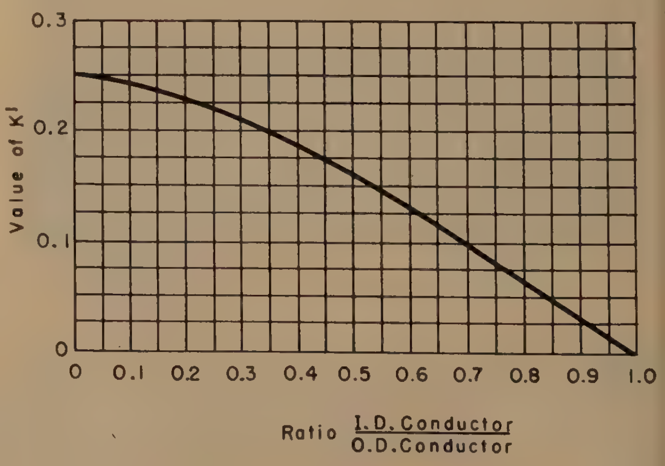

Fig. 2. Values of $K'$ for use in calculation of cable reactance

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*Prof. H. B. Dwight has published general equations covering this situation, which can be used when circumstances require great accuracy, or when large conductors and close spacings are involved; also, in high-frequency work. The complexity of the formulas, however, makes them difficult to handle.

(6). That mutual partial linkages due to the flux produced by cables other than Cable 1 are approximated closely enough for practical purposes by the assumption that such linkages are equal to the total linkages that would exist with a line conductor situated at the center of the actual conductor. Here again where greater precision is required, Dwight's formulas may be used.

### LIST OF SYMBOLS USED IN FORMULAS

$A = \log_e \frac{D_{12}}{r}$

$K' = 0.25$ for concentric stranded, segmental, or solid-conductor cable

$K' = \frac{1-3(a/r)^2}{4[1-(a/r)^2]} + \frac{(a/r)^4}{[1-(a/r)^2]^2} \log_e \frac{r}{a}$ for annular cables

$a$ = inside radius of annular cable conductor (inches)

$r$ = outside radius of cable conductor (inches)

$I_k$ = current in Cable $k$ (amperes)

$I_1$ = current in Cable 1 (amperes)

$D_{12}$ = distance from Cable 1 to Cable 2 (inches)

$D_{1k}$ = distance from Cable 1 to Cable $k$ (inches)

$D_{1(k\text{-}1)}$ = distance from Cable 1 to Cable $k$-1 (inches)

$n$ = number of cables in group

*Note:* $K'$ is plotted in FIG. 2 for convenience in calculation.

### INDUCTANCE AND REACTANCE

The inductance in henrys per 1000 ft is

$$L = 61 \times 10^{-6} \left[ A + K' + \sum_{2}^{n} \left\{ \left( \log_e \frac{D_{1k}}{D_{1(k-1)}} \right) \sum_{1}^{n-1} \frac{I_k}{I_1} \right\} \right] \quad (1)$$

Reactance at 60 cycles in ohms per 1000 ft is

$$X = 0.023 \left[ A + K' + \sum_{2}^{n} \left\{ \left( \log_e \frac{D_{1k}}{D_{1(k-1)}} \right) \sum_{1}^{n-1} \frac{I_k}{I_1} \right\} \right] \quad (2)$$

Since the currents are vectors, in general the summation term in this equation will be complex. Write it equal to $B + jC$.

Then

$$X = 0.023[A + K' + B + jC]$$

Impedance is $R + jX$

where $R$ = conductor resistance, ohms per 1000 ft.

Hence $Z = R + jX = R - 0.023\,C + j\,0.023(A + K' + B)$

The complex expression for reactance simply implies that energy is transferred from one conductor to another. If $C$ is positive, energy is being transferred *to* the conductor, so that the energy loss in the conductor, between its ends, is less than would be expected from the conductor resistance. If $C$ is negative, energy is being transferred *from* the conductor, so the loss is greater than would be expected from the resistance. Of course, the process neither creates nor destroys energy—simply transfers it; so that $\sum C = 0$. The actual energy dissipated per foot is still $I^2R$; the energy transferred is transmitted.

### TECHNIQUE OF CALCULATION

The technique of calculation may be summarized in Table I, where the linkages with Cable 1 are calculated. The first column simply gives an indication of which area (distance) is under consideration. The value of the distance is given in the second column. The fifth column, which is headed "Product", is the product of Columns 3 and 4.

### SIMPLIFICATIONS IN PRACTICAL CALCULATIONS

The foregoing formulas are very general, and can be applied to any cable arrangement, so long as $\sum_{1}^{n} I_k = 0$. They can be applied to cables of different sizes, carrying different currents; these currents may have any phase relationship at all, so long as their magnitudes and phase relationships are known beforehand. Single-phase circuits and three-phase circuits in the same duct bank may also be handled. Such calculations, however, become decidedly involved, and fortunately represent somewhat unusual conditions.

TABLE I: LINKAGES WITH CABLE 1

| Cables | Distance | $\log_e \frac{D_{1k}}{D_{1(k-1)}}$ | $\sum I_k/I$ | Product |
|---|---|---|---|---|
| 1–2 | $D_{12}$ | $A + K'$ | 1 | $A + K'$ |
| 1–3 | $D_{13}$ | $\log_e(D_{13}/D_{12})$ | $1 + I_2/I_1$ | $(1 + I_2/I_1)\log_e(D_{13}/D_{12})$ |
| 1–4 | $D_{14}$ | $\log_e(D_{14}/D_{13})$ | $1 + I_2/I_1 + I_3/I_1$ | $(1 + I_2/I_1 + I_3/I_1)\log_e(D_{14}/D_{13})$ |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| 1–$n$ | $D_{1n}$ | $\log_e(D_{1n}/D_{1(n-1)})$ | $\sum_{1}^{n-1} I_k/I_1$ | $\left[\sum_{1}^{n-1} I_k/I_1\right]\log_e(D_{1n}/D_{1(n-1)})$ |
| | | | | $S$ = sum of product column |
| | | | | $= A + K' + B + jC$ |

Reactance of Cable 1 = $0.023\,S$

$= 0.023\,(A + B + K' + jC)$ ohms per 1000 ft to neutral, at 60 cycles

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(1) Numbered references are listed at the end of the article.

## *TABLE II:* VALUES OF *B*

### Single-phase Circuits

| Arrangement (Fig. 4) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $A_1$ | 0 | 0.346 | −0.346 | −0.405 | 1.097 | 0.458 | −0.234 | 1.842 | 3.398 | 0.628 | −0.213 | 3.205 | 0.905 | 0.517 | 4.939 | 0.783 | 1.047 | 2.531 |
| $A_2$ |  | 0.346 | −0.346 | −0.405 | 0.692 | 0.692 | −0.692 | 0 | 3.174 | −0.287 | −0.213 | 1.496 | −0.804 | 0.804 | 5.188 | −0.064 | − .224 | 1.608 |
| $A_3$ |  |  |  |  |  | 0.458 | −0.234 | 1.150 | 1.097 | −0.980 | −0.213 | 3.205 | 0.905 | 0.804 | 4.090 | −0.575 | − .224 | 0 |
| $A_4$ |  |  |  |  |  |  |  |  |  |  | −0.213 | 1.496 | −0.804 | 0.517 | 1.385 | −1.162 | 1.047 | −0.512 |
| $B_1$ | 0 | 0.346 | −0.346 | 0.692 | 0.692 | 0.458 | −0.234 | 1.150 | 1.097 | −0.980 | 1.496 | 1.496 | −0.804 | 0.517 | 1.385 | −1.162 | 1.896 | −0.512 |
| $B_2$ |  | 0.346 | −0.346 | 0.692 | 1.097 | 0.692 | −0.692 | 0 | 3.174 | −0.287 | 1.496 | 3.205 | 0.905 | 0.804 | 4.090 | −0.575 | 3.579 | 0 |
| $B_3$ |  |  |  |  |  | 0.458 | −0.234 | 1.842 | 3.398 | 0.628 | 1.496 | 1.496 | −0.804 | 0.804 | 5.188 | −0.064 | 3.579 | 1.608 |
| $B_4$ |  |  |  |  |  |  |  |  |  |  | 1.496 | 3.205 | 0.905 | 0.517 | 4.939 | 0.783 | 1.896 | 2.531 |

Certain simplifications can be introduced where all cables are of the same size, all circuits carry currents which are in phase with each other and of the same magnitude, and where, further, all three-phase circuits are balanced, and single-phase and three-phase circuits do not occupy the same duct bank. In such cases, we have the following vector relationships between currents:

Single-phase currents are all of the form $I\,\underline{/0^\circ}$ or $I\,\underline{/180^\circ} = -I$.

Three-phase currents are all of the form

$$I\,\underline{/0^\circ} = I$$

$$I\,\underline{/120^\circ} = aI \qquad a = -\tfrac{1}{2} + \sqrt{3}/2j$$

$$I\,\underline{/240^\circ} = a^2 I \qquad a^2 = -\tfrac{1}{2} - \sqrt{3}/2j$$

and

$$1 + a + a^2 = 0$$

(This is the "symmetrical components" notation(2) and is very easy to handle in such cases as these.)

Here

$$\frac{I_A}{I_A} = 1 \qquad \frac{I_B}{I_A} = a \qquad \frac{I_C}{I_A} = a^2$$

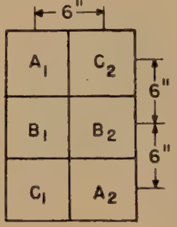

**Fig. 3.** Cable arrangement of two three-phase circuits at 6-inch spacing

## *TABLE III:* VALUES OF *B* AND *C*

### Three-phase Circuits

| Arrangement (Fig. 5) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cable | **Values of B** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| $A_1$ | 0 | 0.174 | 0.346 | −0.285 | 0.921 | 0.055 | 0.574 | −0.022 | 2.392 | −0.055 | 1.151 | −0.114 | −0.110 | 1.268 | −0.225 | 0.205 | 4.562 | −0.521 | 1.121 | 1.339 |
| $A_2$ |  |  |  | −0.285 | 0.921 | 0.055 | 0.574 | −0.022 | 1.589 | −0.916 | 1.496 | −0.229 | −0.034 | 1.727 | −0.402 | 0.205 | 4.562 | −0.521 | 0.217 | 1.843 |
| $A_3$ |  |  |  |  |  |  |  |  |  | −0.055 | 1.151 | −0.121 | −0.057 | 1.727 | −0.402 | 0.205 | 3.108 | −0.521 | −0.301 | 1.955 |
| $A_4$ |  |  |  |  |  |  |  |  |  |  |  |  |  | 1.268 | −0.225 | 0.205 | 3.108 | −0.521 | −0.876 | 1.843 |
| $A_5$ |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1.339 |
| $B_1$ | 0 | 0 | 0 | 0.346 | 0.346 | 0.112 | 0.112 | −0.059 | 1.243 | 0.458 | 0.458 | −0.004 | −0.034 | 0.517 | 0.246 | 0.246 | 2.451 | 0.046 | −0.078 | 0.539 |
| $B_2$ |  |  |  | 0.346 | 0.346 | 0.112 | 0.112 | −0.059 | 1.243 | 0.692 | 0.692 | −0.056 | −0.110 | 0.804 | 0.246 | 0.246 | 2.451 | 0.046 | −0.132 | 0.855 |
| $B_3$ |  |  |  |  |  |  |  |  |  | 0.458 | 0.458 | 0.073 | −0.057 | 0.804 | 0.246 | 0.246 | 2.451 | 0.046 | −0.132 | 0.916 |
| $B_4$ |  |  |  |  |  |  |  |  |  |  |  |  |  | 0.517 | 0.246 | 0.246 | 2.451 | 0.046 | −0.078 | 0.855 |
| $B_5$ |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 0.539 |
| $C_1$ | 0 | 0.174 | 0.346 | −0.285 | 0.921 | 0.055 | 0.574 | 1.240 | 1.589 | −0.055 | 1.151 | −0.285 | −0.201 | 1.268 | −0.402 | 2.451 | 3.108 | 0.046 | −0.876 | 1.339 |
| $C_2$ |  |  |  | −0.285 | 0.921 | 0.055 | 0.574 | 1.240 | 2.392 | −0.916 | 1.496 | −0.100 | −0.201 | 1.727 | −0.225 | 2.451 | 3.108 | 0.046 | −0.301 | 1.843 |
| $C_3$ |  |  |  |  |  |  |  |  |  | −0.055 | 1.151 | 0.052 | −0.483 | 1.727 | −0.225 | 2.451 | 4.562 | 0.046 | 0.217 | 1.955 |
| $C_4$ |  |  |  |  |  |  |  |  |  |  |  |  |  | 1.268 | −0.402 | 2.451 | 4.562 | 0.046 | 1.121 | 1.843 |
| $C_5$ |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1.339 |
| Cable | **Values of C** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| $A_1$ | 0 | 0.300 | 0.600 | 0.300 | 0.997 | 0.503 | 0.804 | 0.351 | 1.045 | 0.504 | 1.201 | +0.096 | +0.008 | 1.314 | 0.263 | 0.513 | 1.994 | 0 | 0.901 | 1.385 |
| $A_2$ |  |  |  | 0.300 | 0.997 | 0.503 | 0.804 | 0.351 | 1.551 | 0 | 1.394 | −0.397 | −0.252 | 1.598 | 0.005 | 0.513 | 1.994 | 0 | 0.309 | 1.709 |
| $A_3$ |  |  |  |  |  |  |  |  |  | 0.504 | 1.201 | −0.301 | −0.419 | 1.598 | 0.005 | 0.513 | 2.796 | 0 | 0 | 1.799 |
| $A_4$ |  |  |  |  |  |  |  |  |  |  |  |  |  | 1.314 | 0.263 | 0.513 | 2.796 | 0 | −0.309 | 1.709 |
| $A_5$ |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1.385 |
| $B_1$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.600 | −0.951 | 0 | 0 | −0.097 | 0.252 | 0 | −0.071 | 1.141 | −1.657 | 0.552 | −1.084 | 0 |
| $B_2$ |  |  |  | 0 | 0 | 0 | 0 | 0.600 | 0.951 | 0 | 0 | 0.097 | −0.008 | 0 | 0.071 | 1.141 | −1.657 | 0.552 | −0.293 | 0 |
| $B_3$ |  |  |  |  |  |  |  |  |  | 0 | 0 | −0.229 | 0.419 | 0 | 0.071 | 1.141 | 1.657 | 0.552 | 0.293 | 0 |
| $B_4$ |  |  |  |  |  |  |  |  |  |  |  |  |  | 0 | −0.071 | 1.141 | 1.657 | 0.052 | 1.084 | 0 |
| $B_5$ |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 0 |
| $C_1$ | 0 | −0.300 | −0.600 | −0.300 | −0.997 | −0.503 | −0.804 | −0.951 | −1.551 | −0.504 | −1.201 | 0.300 | 0.338 | −1.314 | −0.005 | −1.654 | −2.796 | −0.552 | 0.309 | −1.385 |
| $C_2$ |  |  |  | −0.300 | −0.997 | −0.503 | −0.804 | −0.951 | −1.045 | 0 | −1.394 | −0.069 | −0.338 | −1.598 | −0.263 | −1.654 | −2.796 | −0.552 | 0 | −1.709 |
| $C_3$ |  |  |  |  |  |  |  |  |  | −0.504 | −1.201 | 0.600 | 0 | −1.598 | −0.263 | −1.654 | −1.994 | −0.552 | −0.309 | −1.799 |
| $C_4$ |  |  |  |  |  |  |  |  |  |  |  |  |  | −1.314 | −0.005 | −1.654 | −1.994 | −0.552 | −0.901 | −1.709 |
| $C_5$ |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | −1.385 |

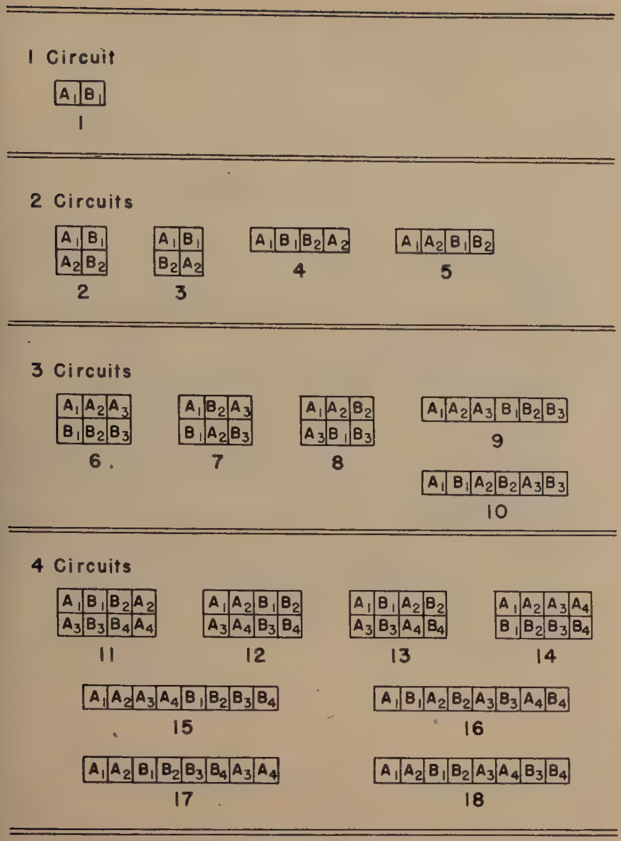

Fig. 4. Eighteen arrangements of cable for single-phase circuits. Numbers relate the individual arrangements to factors in Table II

NUMERICAL EXAMPLE

For the cable arrangement shown in FIG. 3 (wherein the letters refer to phases):

Conductor size 750,000 cir mils, $r=0.5$ in.

$$K'=0.25$$

$$A=\log_e\frac{6}{0.5}=2.485 \qquad A+K'=2.735$$

*Required*: Reactance of Cable $A_1$

| Cables | Distance | $\log_e\dfrac{D_{1k}}{D_{1(k-1)}}$ | $\sum_{1}^{n-1} I_k/I$ | Product |
|---|---|---|---|---|
| $A_1C_2$ | 6 | 2.735 | 1 | $2.735+0j$ |
| $A_1B_1$ | 6 | 0 | $1+a^2$ | 0 |
| $A_1B_2$ | $6\sqrt{2}$ | 0.347 | 0 | 0 |
| $A_1C_1$ | 12 | 0.347 | $a$ | $-0.173+0.300j$ |
| $A_1A_2$ | $6\sqrt{5}$ | 0.112 | $a+a^2$ | $-0.112$ |
| | | | Sum | $S=2.450+0.300j$ |

Here $B=-0.285$ and $C=+0.300$

$X_A=0.023\ (2.450+0.300j)\ =0.0560+0.0069j$

By the same method $X_B\ =0.709+0j$

$X_C\ =0.0560-0.0069j$

Also, by symmetry, $X_{A1}=X_{A2}$; $X_{B1}=X_{B2}$; $X_{C1}=X_{C2}$

PARALLEL CIRCUITS

As a rule, when circuits are paralleled, there will be no appreciable effect on phase balance produced by unbalanced cable impedance. However, the difference in impedance between cables in parallel may result in an unbalance of current between such cables.

The procedure is to solve for the impedance of each cable, assuming balanced currents, and then to calculate the unbalance of currents due to difference in impedance. If this is considerable, or if a high degree of precision is required, the currents thus obtained may be used in the foregoing equations, and the process repeated. This can be done as many times as is necessary to give the required accuracy in the answer. Usually one or, at most, two repetitions are sufficient.

ARRANGEMENTS COMMONLY MET IN PRACTICE

Of the various arrangements that have been encountered in practice, the following have been worked out for specific applications. Many of them are quite common. FIG. 4 and Table II cover single-phase circuits and FIG. 5 and Table III cover 3-phase circuits.

SHEATH VOLTAGES

If a cable is operated with open-circuited sheath, the sheath voltage is given by the expression

$$E_S=I_CX_M \tag{5}$$

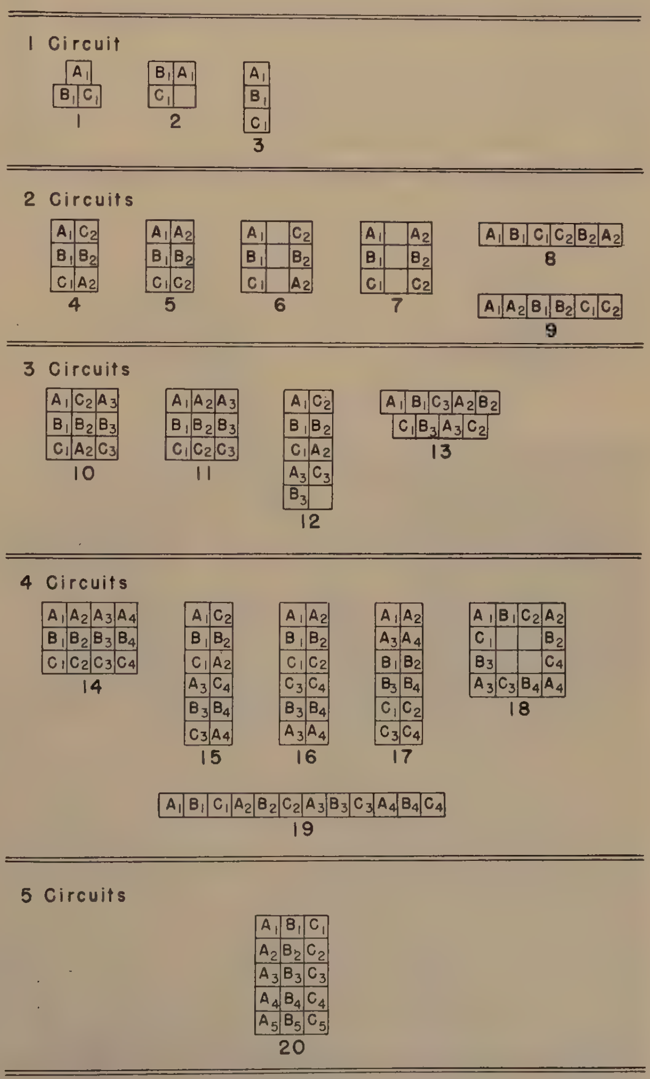
1 Circuit
A1 / B1 C1
1
B1 A1 / C1
2
A1 / B1 / C1
3
2 Circuits
A1 C2 / B1 B2 / C1 A2
4
A1 A2 / B1 B2 / C1 C2
5
A1 C2 / B1 B2 / C1 A2
6
A1 A2 / B1 B2 / C1 C2
7
A1 B1 C1 C2 B2 A2
8
A1 A2 B1 B2 C1 C2
9
3 Circuits
A1 C2 A3 / B1 B2 B3 / C1 A2 C3
10
A1 A2 A3 / B1 B2 B3 / C1 C2 C3
11
A1 C2 / B1 B2 / C1 A2 / A3 C3 / B3
12
A1 B1 C3 A2 B2 / C1 B3 A3 C2
13
4 Circuits
A1 A2 A3 A4 / B1 B2 B3 B4 / C1 C2 C3 C4
14
A1 C2 / B1 B2 / C1 A2 / A3 C4 / B3 B4 / C3 A4
15
A1 A2 / B1 B2 / C1 C2 / C3 C4 / B3 B4 / A3 A4
16
A1 A2 / A3 A4 / B1 B2 / B3 B4 / C1 C2 / C3 C4
17
A1 B1 C2 A2 / C1 B2 / B3 C4 / A3 C3 B4 A4
18
A1 B1 C1 A2 B2 C2 A3 B3 C3 A4 B4 C4
19
5 Circuits
A1 B1 C1 / A2 B2 C2 / A3 B3 C3 / A4 B4 C4 / A5 B5 C5
20

Fig. 5. Twenty arrangements of cable for three-phase circuits. Numbers relate the individual arrangements to factors in Table III

(Continued on next page)

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## TECHNIQUE FOR CALCULATING

(Continued from preceding page)

where $E_S$=induced voltage in the sheath, volts per 1000 feet

$I_C$=conductor current, amperes

$X_M$=mutual reactance between conductor and sheath, ohms per 1000 feet

$X_M$ is given by the equation

$$X_M = 0.023\ (A' + K + B + jC) \qquad (6)$$

Here $A' = \log_e \dfrac{D}{f}$

$$K = 1 - \left[\frac{1}{(f/e)^2 - 1}\right] \log_e \frac{f}{e} \qquad (7)$$

$f$=outside radius of sheath, inches
$e$=inside radius of sheath, inches

The derivation of Equation (7) is given in the Clark and Shanklin paper⁽³⁾.

$B$ and $C$ may be taken from Tables II and III.

$K$ is plotted in Fig. 6.

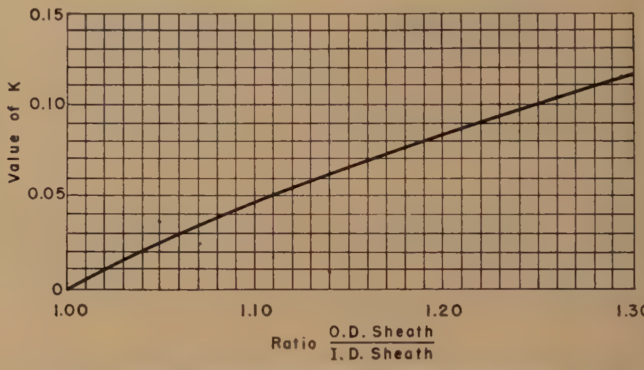

**Fig. 6.** Values of $K$ for use in calculations of mutual reactance in determining sheath voltages

The calculation of sheath losses with short-circuited sheath is a rather involved process, and is beyond the scope of this article. Halperin and Miller⁽⁴⁾, however, cover some of the more common cases in detail, and give a general theory.

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(3)"High Tension Single Conductor Cable for Polyphase Systems" by W. S. Clark and G. B. Shanklin, *Trans. AIEE*, 1919, p. 663.

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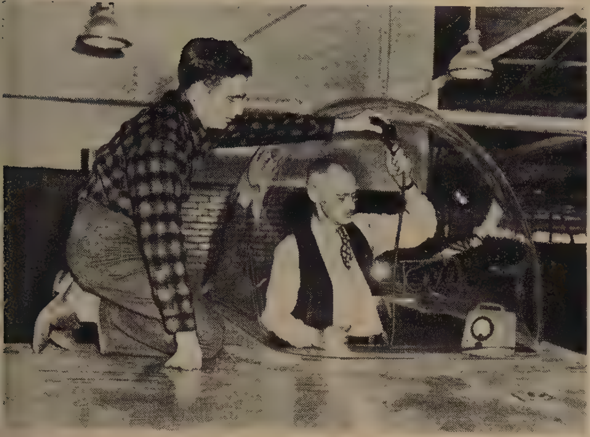
(5)L. F. Woodruff: *Electric Power Transmission and Distribution*, John Wiley & Sons, Inc. 1925, p. 22.

# HIGH LIGHTS AND SIDE LIGHTS

## Skin Test of Helicopter Cockpit Cover



*Thickness of this plastic structure is tested by reading the separation between a steel block held against the outside surface and the instrument head inside at points where the thickness is to be measured. By this means, variations of as little as five percent from the desired thickness can be detected*

## Flight Recorder

A new type of flight recorder (FRONTISPIECE,) which automatically records air roughness, altitude, and operation of automatic pilot and de-icing equipment on aircraft, will be installed on a DC-3 aircraft under a test program directed by the Air Transport Association. It is expected that use of flight recorders will provide commercial airlines with increased information on their flight operations and make possible greater operational control.

The result of more than two years of development and testing, the instrument makes a record of flight data from take-off to landing, and is so accurate in measuring altitude that it indicates changes as small as ten feet.

The actual record is made by a stylus, which scratches through a thin coating on a slowly moving strip of paper and leaves a black trace.

## World's Largest Supersonic Wind Tunnel

The world's largest supersonic wind tunnel, capable of producing winds of about 1500 mph, has been unveiled at the Lewis Flight Propulsion Laboratory in Cleveland by the National Advisory Committee for Aeronautics. The tunnel will be used by the government's aeronautical research agency in the study of supersonic power plants.

Features of the wind tunnel are an axial-flow air compressor with more than a thousand blades, the most mechanical power ever placed on a single shaft by electric motor drive, and the three largest slip regulators yet devised.

Speed of the winds through the tunnel's 6 by 8-ft test section is regulated by a pliable sheet of stainless steel that forms part of the entrance to the tunnel. This sheet is positioned by means of hydraulic rams that adjust it to varying curvatures to narrow or widen the throat through which the wind is forced.

Wind is created by the air compressor when it is driven by three 29,000-hp electric motors hooked in tandem to a single drive shaft. The motors, which operate at 900 rpm, are the largest ever built to run at that speed. Their 87,000-hp total is the greatest ever used in a wind-tunnel installation; efficiency rating of the motors is approximately 97 percent.

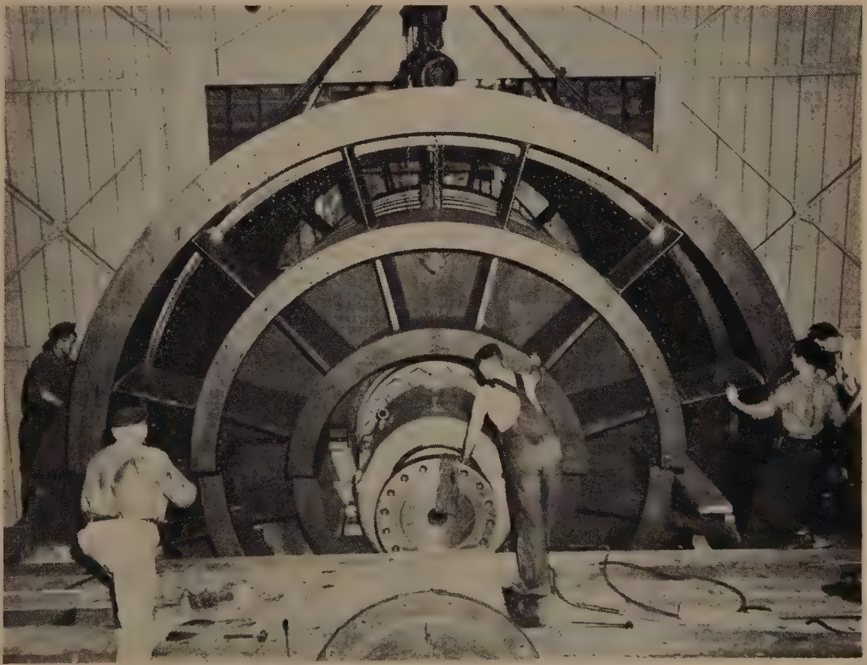
The motor stators are connected to a three-phase transformer and circuit breakers are located in the primary winding to allow the motor-transformer combination to be switched in as a unit.

Stable operation of the motors is insured by slip regulators of the liquid-rheostat type. Because of the size of the motors it was necessary to build regulators that are physically the largest, carry the highest electric current, and dissipate the greatest power, of any ever designed.

Each of the three drive motors is governed by its own regulator, with the regulator for the first one acting as a master, the other two acting as followers. Each regulator consists of movable electrodes connected mechanically to a hoist mechanism and electrically through an electrolytic salt solution to form a Y and neutral circuit external to the motors. Equal values of resistance can be placed in this circuit for each phase by moving the electrodes closer together or farther apart. Positioning is done by means of a reversible d-c motor on each regulator, the power and control furnished by amplidynes.

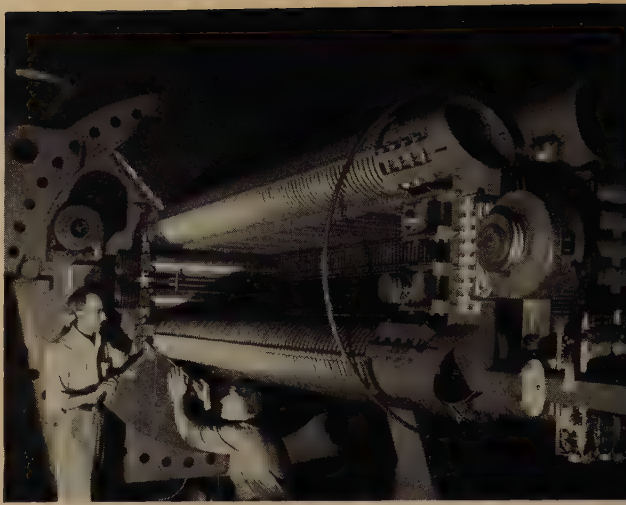
The slip regulators change the resistance in the secondary winding circuit to alter the amount of current supplied to the drive motors. This changes the speed according to the characteristics of the compressor.

(Continued on next page)



Three motor units capable of a total of 100,000 hp are coupled on a single shaft to drive this axial-flow blower, shown here partially installed in the world's largest supersonic wind tunnel

These rheostats also regulate the starting sequence of the drive motors. The excessive current drawn by the drive motors makes it necessary to start them individually, letting each one reach 50 percent of full primary load before allowing the next one to be cut in.



*Electrostatic charges by this accelerator will be carried from one end of the machine to an aluminum sphere at the other end by two moving belts, not yet installed, which will travel between the two long tubes shown in the foreground. A steady stream of protons will be sent through the accelerator tube to a target, where the reaction is studied*

## Electrostatic Accelerator

A 3,500,000-volt electrostatic accelerator is now under construction for the Brookhaven National Laboratory at Upton, Long Island (N. Y.).

One of several electronuclear machines planned for the Brookhaven atomic research center, the accelerator will be used for a variety of fundamental studies of the atomic nucleus. In some experiments, high-energy particles from the accelerator will be employed to study the processes of "chipping" or "splitting" atomic nuclei into fragments such as the radioactive isotopes now widely applied in research.

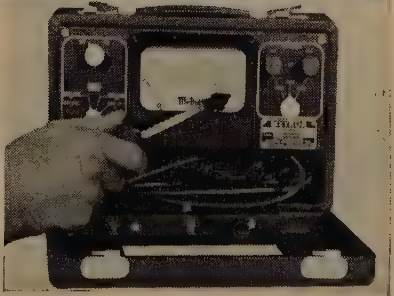
Though the electrostatic accelerator has an output energy considerably lower than such machines as the synchrotron, betatron, and cyclotron, it has the advantage of supplying high-speed atomic particles at a uniform energy, to permit accurate measurement of fundamental constants vital in studies of the nucleus of an atom.

The entire machine, in a 30,000-lb steel tank 18 ft long and 8 ft in diameter, will be housed in a specially constructed building, with 2-ft-thick concrete walls.

## Summer Science Fellowship

Applications for study during the summer of 1949 under the six-week General Electric Science Fellowship Program are now being accepted by officials of Union College at Schenectady (N. Y.) and Case Institute of Technology in Cleveland (O.).

Special courses, designed to bring information concerning the latest developments in chemistry and physics to 100 science teachers selected on a competitive basis from 19 northeastern states and the District of Columbia, will be conducted by the college faculties in co-operation with scientific staffs of the General Electric Company in Schenectady and Cleveland.



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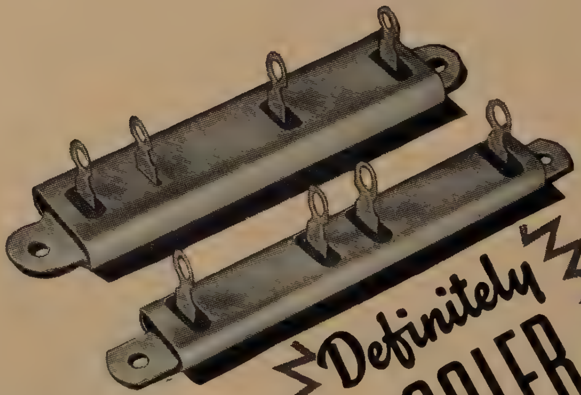

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Fellowships will cover traveling exenses to and from the college, living xpenses while attending the session, and uition and fees. Formal announcements re being mailed to secondary schools nd science teachers in the 19 states. Application forms may also be secured by writing the college serving either of the wo areas.

The fifth annual session at Union Colege, to be held July 2 through August 13, s open to 50 teachers of chemistry and physics from New England, New York, Pennsylvania, New Jersey, Delaware, Maryland, Virginia, and the District of Columbia. Completed applications must be submitted before April 1 to the Secretary, Committee on General Elecric Fellowships, Physics Laboratory, Union College, Schenectady 8 (N. Y.).

At Case Institute of Technology the hird annual course is to be held June 27 hrough August 5, and is open to 50 eachers, of physics only, from Ohio, West Virginia, Kentucky, Indiana, Illiois, Wisconsin, Michigan and western Pennsylvania. Applications must be submitted before April 1 to Dr. Elmer Hutchisson, Case Institute of Technology, Cleveland 6 (O.).

### Call for Heavy Scrap

In letters to business-paper editors and officials of trade associations and chambers of commerce, Secretary of Commerce Charles Sawyer has urged wholehearted ndustrial participation in the national drive now under way for iron and steel eavy scrap, and has asked for help in nforming the nation's business executives f the need for substantial additional quantities of heavy scrap to insure full teel and foundry production and accumuate necessary scrap reserves.

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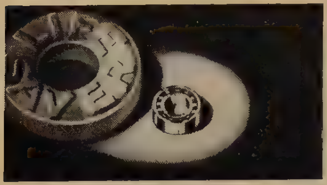
## Miniature Ball Bearing



A new miniature ball bearing is now being offered with a convenient bore-to-o.d. relation. This bearing, which fits on a ⅛-in. shaft, needs only a ¼-in. housing, bringing the space requirements well within that which is possible with a plain bearing or bushing but affording all the advantages of antifriction operation. The illustration shows the bearing compared to a candy life saver; both are actual size. The bearing is of the full-race radial type with 1-mm balls. It is made in both chrome alloy bearing steel and 440 stainless, and weighs but ¼ of a gram.—*Miniature Precision Bearings, Inc., Keene, N. H.*

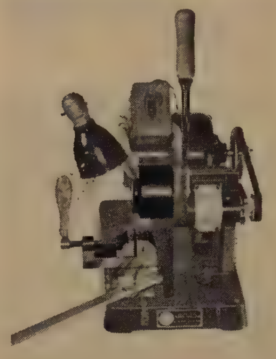
## Lamp

A new 75-watt R-30 spot lamp (reflector 3¾ in. in diameter) and a new flood lamp of the same size, designed to meet the demand for smaller, lower-wattage lamps than were previously available. These lamps help to round out the present line of reflector lamps, expanding their usefulness in many applications, such as spot and floodlighting in stores, office and public buildings, theaters, restaurants, homes, and industrial buildings. Because of their small size, they permit the design of individual holders and housings which, with due regard to safe temperature limits, are smaller than those required for the R-40 lamps. They have a rated life of 1000 burning hours.—*General Electric Co., Lamp Department, Cleveland, Ohio.*

## Rotary Snap Switch

The Esco Type P, Style 30 H and 10 H, quick-make quick-break rotary snap switches with explosion-proof dust-tight vapor-tight weatherproof housings for hazardous locations. The assembly may be surface-mounted with the switch handle on the dome, or it can be furnished with the switch shaft inverted and projecting through the base for panel mounting. Housings are standard Crouse-Hinds Type EMS cases with an aluminum dome which screws onto a cast-iron base. Standard conduit connections—¾ in. for the shallow case and 1 in. for the deep case—are provided.—*Electro Switch Corp., Weymouth 88, Mass.*

## Cutting Machine Attachments



Two new attachments have recently been developed for the Rouse hand miller, a high-speed ball-bearing motor-driven machine made for handling light cuts in brass, aluminum, and similar materials. The No. 7 vise, which increases the range and productive ability of the machine, is fitted with a specially slotted removable jaw, enabling it to hold odd-shaped pieces. This vise can be converted into an economical jig for use on other equipment. The No. 9 cast-iron safety cutter guard can be located or adjusted to the left or right, as required by a particular job, protecting the operator's hands against injury. For further efficiency and convenience, this guard can be drilled for a coolant fitting which will convey the coolant directly to the cutting tool.—*H. B. Rouse & Co., 2214 N. Wayne Ave., Chicago 14, Ill.*

## Rotary Drill

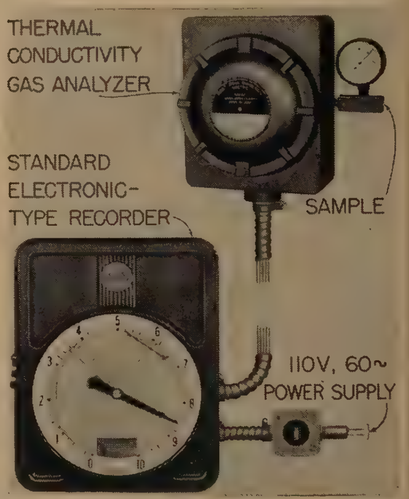
A new and improved rotary concrete drill with design features that make possible a substantial cost-per-hole saving. Because of the core-drill design and a side-exhaust slot which permits core particles to escape, the drill penetrates concrete at the rate of two inches or more per minute in diameters of from ¼ in. to 2 in. Specially treated sintered-carbide cutters—located around the perimeter of the core where they operate at the most efficient speed—exert a quiet, pulverizing action which drills holes faster and leaves them straighter and cleaner. The drill bit is designed for use with ordinary electric drill motors.—*Tilden Tool Mfg. Company, 1995 No. Fair Oaks Ave., Pasadena 3, Calif.*

## Resistors

A complete line of extremely small Carbo-film resistors designed for use in the manufacturing of all types of miniature electronic units. They are available in sizes from ¼ to 1 watt, in values from 20 ohms to 5 megohms, and with tolerances of ½ to 1 percent. The smallest resistor in the line measures $\frac{1}{16}$ in. diameter over caps, ⅜ in. over-all length, with 1½ in. tinned-copper leads. They also can be supplied insulated.—*Wilkor Products, Inc., 3835 West 150th St., Cleveland 11, Ohio.*

## Gas Analyzer

A line of automatic gas analyzers and recorders has been expanded to include a thermal-conductivity-type gas analyzer. The new analyzer is mounted in an explosion-proof case and is unaffected by voltage variations, ambient temperature, and variations in sample pressure. An all a-c circuit is employed, permitting the use of the Bailey electronic recorder which does not require dry batteries or a standard cell. The analyzer is unusually stable, fast in response, and requires no manual attention or adjustment except for routine maintenance.—*Bailey Meter Co., 1050 Ivanhoe Rd., Cleveland 10, Ohio.*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## Stepping Switch

A new high-speed spring-driven stepping switch with from one to ten bank levels, each comprising 26 contacts. A pair of double-ended wiper springs is stepped over each bank level, which occupies only 180 degrees; thus, one end of the wipers is always free of the bank contacts and the other end is always in engagement with the bank. Upon completion of the operating cycle, the switch may be allowed to remain in place, to be homed, or returned to normal.

New features include: molded bank levels the dimensions of which are controlled with extreme accuracy; a lightweight rotor which reduces mechanical inertia; and keyed rotor parts which prevent shifting. A switch also is available which provides for 52-point selection over a maximum of five contact levels.—*C. P. Clare & Co., 4719 W. Sunnyside Ave., Chicago 30, Ill.*

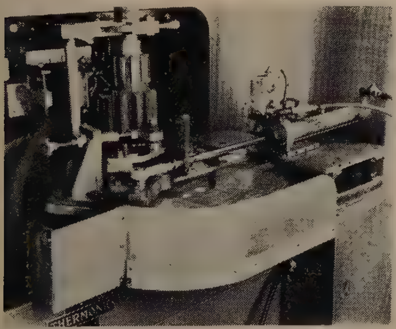
### Slide Projector

A new slide projector, Type PF-3-C, for use in television stations to supply still-projection facilities complementing 16-mm and 35-mm motion-picture equipment. The instrument will accept standard 3¼- by 4½-in. slides and cards, or 4-in.-wide strips of any length.

Providing for dissolves between dual sections, the projector has dual lenses and can be ordered to operate with large iconoscope, small iconoscope, or image orthicon types of pickup cameras. With its dissolving-action feature and iris control, the two images can be superimposed one on the other or projected singly or simultaneously in any relative brightnesses. Its light intensity is between 10- and 15-foot-candles.—*Transmitter Division, General Electric Co., Electronics Park, Syracuse, N. Y.*

### Gear-hardening Machine

An automatic heating, quenching, and indexing unit for hardening of gear teeth—one tooth at a time—by induction heating. Handling operations involve only the insertion and removal of gears. Because of their size, gears which would require very large equipment to be hardened in one operation can now be done with 20-kw equipment and the use of this machine. The unit accommodates gears ranging from 20 in. in diameter with a 12-in. face or larger, depending on generator capacity.—*Induction Heating Corp., 181 Wythe Avenue, Brooklyn 11, N. Y.*

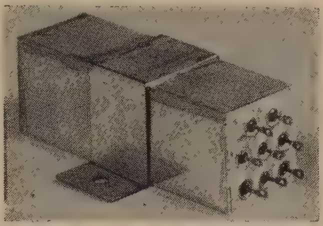


### Temperature-indicating Products

Additional temperature ratings of Tempilstiks (crayons), Tempilaq (liquid), and Tempil Pellets to provide industry with a fuller range of these temperature-indicating products. All three are now available in 12½-deg intervals from 113 to 400 F; Tempilaq for 400 to 1600 F are available in 50-deg increments; and Tempil Pellets are obtainable up to 1700 F.—*Tempil Corp., 132 West 22nd St., New York 11, N. Y.*

### High-speed Relay

The ultrahigh-speed Millisec relay formerly offered single-pole, double-throw, is now made 4-pole, double-throw and is hermetically sealed. These new multipole relays will operate as fast as ½ ms; they have a life expectancy of 22 to 100 million operations, and a contact rating of 110 volts, d-c, 1.2 amp. They are particularly useful for high-speed keying in aircraft or on shipboard, and they are used also in high-speed computers, business machines, high-speed commutators, and for other similar applications.—*Stevens-Arnold Inc., 22 Elkins Street, South Boston 27, Mass.*



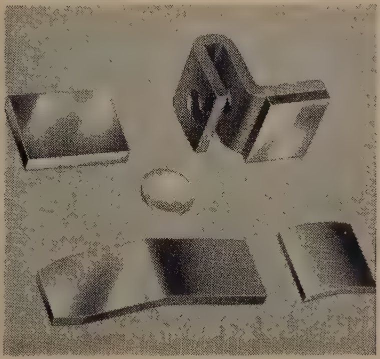
### Ion Chamber Charger-Reader

A new Model 2050 charger-reader designed for use in conjunction with pocket-type ionization chambers. The ionization chambers are used as health-monitoring devices in the presence of gamma or x-ray types of radiation.

The functions of the device are twofold: it will charge the ion chamber to a known voltage; and it will measure the residual chamber charge after exposure to radiation. All "charge" and "read" observations are made on a three-inch meter with a linear scaler. Accuracy is ± 2½ percent of full scale. Operation is simple; the regulating circuits will allow stable operation with an a-c power variation of 95 volts to 130 volts.—*Nuclear Instrument & Chemical Corp., 223 West Erie St., Chicago 10, Ill.*

### Contacts

Electrical contacts UW6 made from copper tungsten by the powder-metallurgy process interrupt heavy currents with minimum erosion. For their efficient performance, high contact forces, and sliding, wiping action on opening and closing are recommended. They exhibit outstanding resistance to galling and wear under these conditions. Typical applications include: air circuit-breaker arcing tips and intermediate contacts, oil-circuit-breaker arcing tips and current-carrying contacts, oil-immersed contactor contacts, and oil-immersed transformer tap-changer contacts.—*Gibson Electric Company, 8352 Frankstown Ave., Pittsburgh 21, Pa.*



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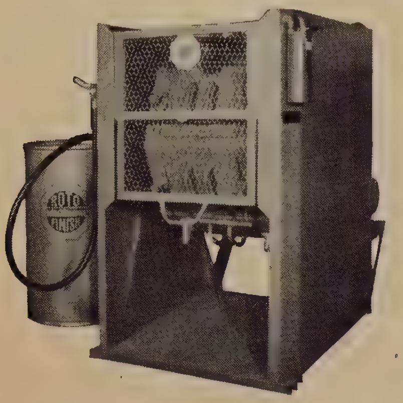
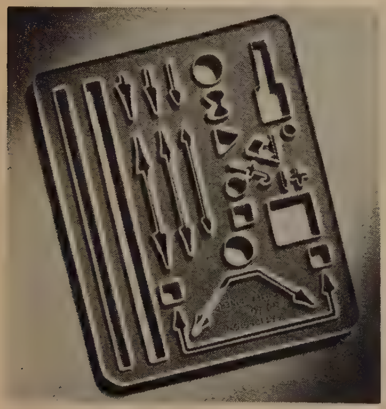
## Finishing Machine

A new 8-door machine for finishing parts whose size and shape are not adapted to standard Roto-Finish processing methods. The machine is built as special equipment for individual requirements, with each flat of the octagon cylinder fitted with a large-size door. Parts are rigidly fixtured to the back of each door, so that surfaces to be finished are presented to the processing mass. Selective action caused by one-direction processing is overcome by reversing cylinder rotation. Doors and fixture plates are interchangeable to handle a multiple of different parts, all of which may be processed at one time. Doors are unlined or rubber lined.—*The Sturgis Products Co., Sturgis, Mich.*



## Drafting Template

A new template, Dimensioner No. 60, for use in all phases of drafting, speeds up the call-out, dimensioning, and lettering of drawings. It makes standard drafting symbols easily, neatly, and accurately, all symbols and sizes conforming to standard drafting-room practice. Made of 0.040 super-quality cellulose nitrate, the beveled cutouts of symbols are precision-milled to give utmost in accuracy.—*Rapidesign, Inc., P. O. Box 592, Glendale, Calif.*



## Shaft Seals

New rotary shaft seals, Series 1100, designed to meet the needs of manufacturers of radio, television, communication, and electrical circuit controlling apparatus, for waterproofed and moisture-sealed rotating shafts. They can be used with remote-controlled devices such as receivers and transmitters.

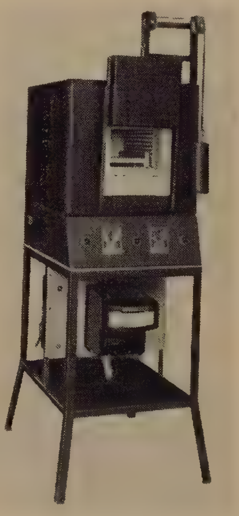
These miniature seals combine the flexibility of rubber in shear and the sealing quality of rubber vulcanized to metal with the low frictional resistance of metal against graphite and the corrosion resistant quality of high-grade brass and bronze.—*H. & H. Buggie and Co., Madison Ave. and 22nd Sts., Toledo, Ohio.*

## Heating Torch

The Crown torch of seamless steel tubing with chrome finish is a tool for practically all heating operations from fine silver-soldering to light brazing. The torch is designed to operate eight hours at a temperature of 2800 deg, and at a cost of less than five cents. This tool, which carries the ICC seal of safety and approval, has an all-in-one tip that eliminates the need for extra tips and tip changes. It also has fingertip control of flame size and temperature.—*Sully Engineering Ltd., 9304 Santa Monica Blvd., Beverly Hills, Calif.*

## Electric Furnace

A new floor-model electric furnace No. 11FM designed specifically for tool and die work, hardening and drawing, and ash analysis. The furnace affords to other applications practical heat control over the entire range from room temperature up to and including 2000 F. Temperature control is achieved by means of two Infitrols. These stepless input controllers are mounted onto the base of the furnace, and another control is mounted beneath the furnace itself. The top and bottom comprise one set of heating elements with the two sides making up a second set.—*K. H. Huppert Co., 6830 Cottage Grove Ave., Chicago 37, Ill.*



## Centrifugal Pump

A new centrifugal pump, Model H, designed especially for applications where moderate pressures and volumes are required from a centrifugal pump running at 1725 rpm. The performance curve shows a shut-off pressure of 19 psi, 10 gpm at 15 psi, 15 gpm at 10 psi, and in excess of 20 gpm at free flow.

The pump is constructed in either bronze or aluminum, with lifetime mechanical rotary seal. Units are available with motors ranging from ⅙ to ⅓ hp, depending on operating range desired.—*Eastern Industries, Inc., 296 Elm St., New Haven 6, Conn.*

## Fractional-hp Motor

A new explosion-proof, Type KC, single-phase capacitor-start fractional-horsepower motor for gasoline vending pumps. The motor, designed for horizontal mounting, is available in ratings of ½ hp 1725 rpm, 60 cycle, and ⅓ hp, 1425 rpm 50/25 cycle, 115/230 volts a-c.

The motor's high starting torque makes possible quick, positive pump starts. Built-in features, such as an automatic reset overload protective device, voltage selector switch, and ON-OFF line switch, assure safe operation, long life, and ease of assembly to pump. The motor has large oil reservoirs filled with oil-saturated wool packing. This provides for minimum servicing; only 30 to 70 drops of oil are required at the end of each 1000 hr of normal operation.—*General Electric Co., Fractional Horsepower Motor Divisions, Schenectady 5, N. Y.*

## Photoelectric Control

A new single-unit outdoor-lighting-control photoelectric relay, Series 62405, for interval night illumination consists of a light-sensitive photorelay and a built-in time-switch. The photorelay turns on the lights at a preset value of daylight, and the automatic time-switch turns them off at any preset time during the night. The time-switch can also be set to turn on the illumination early in the morning if desired.

The advantages of this unit are its compact size and dependable action regardless of weather, location, or time of day. Its performance provides full value from each billboard or other form of outdoor advertising; it keeps illumination levels well above danger mark in busy work areas where installed.—*Fisher-Pierce Co., 45 Ceylon St., Boston, Mass.*

# TRADE LITERATURE

UTTERS—A small folder illustrates and ummarizes the respective uses of three IandKlip cutters for cutting steel strap-ing, wires, rods, bolts, etc. Six pages.—*I. K. Porter, Inc., Sommerville 43, Mass.*

IE TRYOUT ASSEMBLY—Over 20 photo-raphs and drawings graphically illustrate ow a single diemaker can quickly and fficiently test alignments of dies, drill unches in place, tap for screw holes, and nake visual inspection with the Moore die ipper. Eight pages.—*Moore Special Tool o., Inc., 740 Union Ave., Bridgeport 7, onn.*

IEAT-TRANSFER SYSTEMS—The major im-rovements in the fundamental design of an lectric heat-transfer system for processing hemicals, plastics, and rubber offer several dvantages, each of which is described. itled "A New Achievement in Electric Ieat Transfer." Four pages—*Gerin Manu-acturing Co., Inc., 683 Broadway, Newark , N. J.*

AMP HOLDERS—Miniature sketches effec-ively present application possibilities of he Steberlite, a lampholder consisting of hree basic units—the holder, an adapter ox for a cluster of up to five holder units, nd a pole slip fitter for use on either a ½- or 2-in. pipe. Specifications and prices re given. Bulletin 120. Four pages.—*Steber Ianufacturing Co., 2700 Roosevelt Road, Broadview, Maywood, Ill.*

INSULATION-RESISTANCE TESTER — The characteristics, ranges, and applications of heavy-duty-type hand-driven, motor-driven, and multivoltage instruments are detailed in a manner which should simplify the selection of proper instruments for specific insulation-resistance-measuring problems. The text is amply illustrated and aided by charts and diagrams. Bulletin 21–20–16. Twenty-four pages.—*James G. Biddle Co., 1316 Arch St., Philadelphia 7, Pa.*

MAGNETIC AMPLIFIER—The circuits of the amplifier are described, together with its characteristics and various applications. Bulletin VT-2000. Thirty-two pages.—*Vickers Electric Div., Vickers, Inc., 1815 Locust Street, St. Louis 3, Mo.*

PLASTIC SURFACING—Full-color pictures of Textolite installations, together with instructions for applying to furniture tops and fixtures, supplement the text which describes how this plastic surfacing material is made. The 39 available patterns are also shown in color. Bulletin CDP-588. Twelve pages.—*General Electric Company, Chemical Dept., Pittsfield, Mass.*

SOLDERING—Step-by-step cartoons and descriptive text in a 3¼- by 5¾-in. handbook titled "Soldering Tips" designed to instruct beginners and refresh the memories of professional solderers with simplified time-saving soldering methods. Price 10¢. Twenty pages.—*Weller Manufacturing Co., Packer St., Easton, Pa.*

STAINLESS STEEL—A paper-bound publication covering mechanical properties, forming characteristics, and processing after forming. These subjects comprise the first three chapters of the book, "Forming of Austenitic Chromium-nickel Stainless Steels," which was reviewed in February 1949 GE REVIEW. Twenty-six pages.—*International Nickel Co., Inc., 67 Wall St., New York 5, N. Y.*

STEAM GENERATORS—The operating principles and design characteristics are presented with special consideration given to automatic firing sequence, electronic controls, flame characteristics, construction details, performance data, and standard ratings for both steam and hot-water generators in sizes ranging from 10 to 300 hp. Bulletin P-1. Six pages.—*Cyclotherm Corp., Dept. 99R, 90 Broad St., New York 4, N. Y.*

THY-MO-TROL DRIVE—Pertinent facts about Type H1 Thy-Mo-Trol, such as low cost, wide speed range, ratings through ½ hp, and d-c flexibility from a-c power, are enlarged upon. One of the many typical applications is illustrated. GEA-5179A. Four pages.—*General Electric Co., Apparatus Dept., Schenectady 5, N. Y.*

WOOD PROTECTION—The story of wood decay titled "Protecting Your Investment in Wood" explains how and why decay occurs, and shows treating methods to prevent this loss. Four pages.—*Chapman Chemical Co., Suite 770, Dermon Bldg., Memphis 3, Tenn.*

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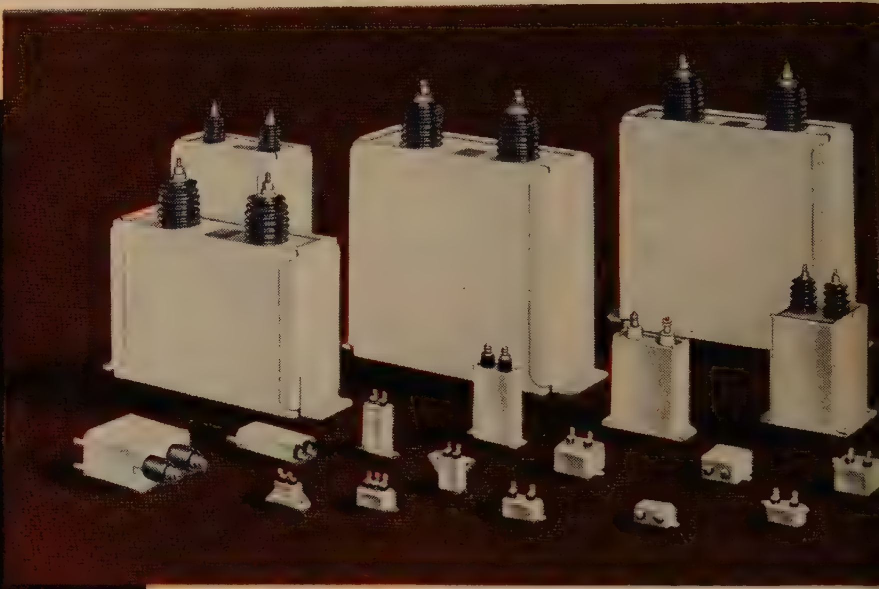


Readily available for DC electronic applications, these capacitors are manufactured in accordance with joint Army-Navy specifications JAN-C-25. Case styles include types CP 53, CP 54, CP 55, CP 61, CP 63, CP 65, CP 67, CP 69 and CP 70. Capacitance ratings are from .01 Muf to 15 Muf, and voltage ratings are listed from 100 to 12,500 volts.

These capacitors are constructed with thin Kraft paper, oil or Pyranol* impregnated, which provides stable characteristics and high dielectric strength. Plates are aluminum foil, manufactured according to detailed specifications. Special bushing construction provides for short internal leads, preventing possible grounds and short circuits. The cases have a permanent hermetic seal to provide longer life. A variety of mounting arrangements are available for various installation requirements. Write for detailed description and operating data: Bulletin GEA-4357A.

*Pyranol is General Electric's non-inflammable liquid dielectric for capacitors.

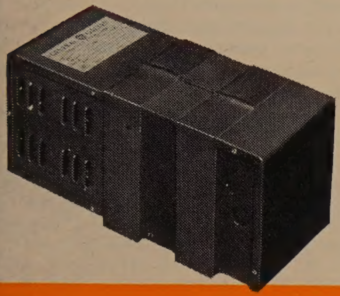
## SAVE SPACE CUT COSTS

Less than one inch long, and only one inch square, this postage-stamp-size selenium rectifier offers radio builders substantial savings in production costs. Only two soldering operations and a minimum of hardware are necessary for installation in places where a rectifier tube and socket won't fit. They're built to safely withstand the inverse peak voltages obtained when rectifying (half-wave) 110-125 volts, rms, and feeding a capacitor as required in various radio circuits. Tests prove that selenium rectifiers will outlast the conventional type of rectifier tubes, at the same time costing less. Send for bulletin GEA-5238.

**GENERAL ELECTRIC**

# Digest

# TIMELY HIGHLIGHTS ON G-E COMPONENTS

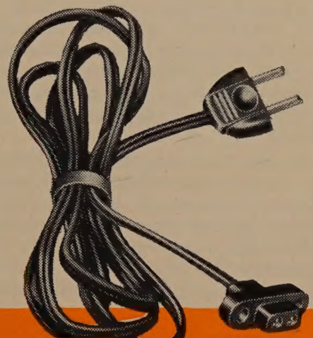


## HOLDS OUTPUT VOLTAGE CONSTANT

This 500-va voltage stabilizer is suit-
ble for a wide variety of electronic
pplications where constant voltage is
emanded. Voltage variations from 95
o 130 volts are absorbed almost in-
tantaneously and output voltage main-
ained at 115 volts (plus or minus 1
ercent). There are no moving parts,
o adjustments to make. This unit will
perate continuously at no load or short
ircuit without damage to itself. It will
imit the short circuit current to approx-
mately twice stabilizer's normal full
oad current rating. Other sizes avail-
ble range from 15 to 5000 va. For
etails, check bulletin GEA-3634B.

## WANT TO TIME TUBE LIFE?

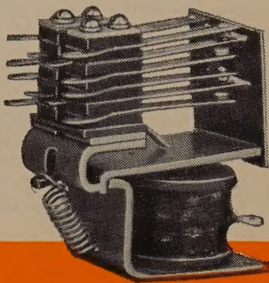
Suitable for installation in radio trans-
itters, these G-E time meters provide
ccurate record of tube operating time.
They record in hours, tenths of hours, or minutes. Ratings range from 11 to 460 volts. Installation on a panel or switchboard is simplified by quick-wiring leads. Timer harmonizes with other panel instruments in appearance and size. Dependability is assured by Telechron* motor drive. Also available for portable use or conduit and junction box mounting. Check bulletin GEC-472.



## FOR YOUR TELEVISION SETS

General Electric's television cord set comes in 6-foot lengths, made of 2/18 Pot-64 brown Flamenol* rip-cord. Set has brown plastic plug and new brown Flamenol connector molded on opposite end. Rip-cord has smooth finish, resists oil, water, acids, alkalies, or sunlight deterioration. Rating is 7 amps., no. 18 wire. Set is designed for assembly on television receiver rear panel, automatically disconnects when panel is removed. Write for further information.

*Trademark Reg. U. S. Pat. Off.



## DEPENDABLE CONTROL FOR AUTOMATIC DEVICES

G.E.'s multi-contact relays are inexpensive units built specifically for appliances and vending machines. Construction features assure quiet, reliable operation, and compactness makes them adaptable to a variety of devices such as coin changers, phonographs, and television receivers. Single-circuit contacts or combinations of contacts for multi-circuit application are attached to the same sturdy frame and coil assembly, affording a multiplicity of relay forms. Ratings are 5 amperes at 115 volts or 24 volts, a-c or d-c. Get details from Bulletin GEC-306.

**General Electric Company, Section D667-1**
**Apparatus Department, Schenectady, N. Y.**

Please send me the following bulletins:

- ☐ **GEA-3634B Voltage Stabilizers**
- ☐ **GEA-4357A D-C Capacitors**
- ☐ **GEA-5238 Selenium Rectifiers**
- ☐ **GEC-306 Multi-contact Relays**
- ☐ **GEC-472 Tube Timers**

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# BOOK REVIEWS

*(Available books may be purchased through the GENERAL ELECTRIC REVIEW for domestic delivery; none sent on approval.)*

### ORGANIC REAGENTS USED IN GRAVIMETRIC AND VOLUMETRIC ANALYSIS
(Chemical Analysis: Vol. 4)

John F. Flagg—Interscience Publishers, Inc., New York. 1948. 314 pp. $6.00.

According to the author's preface, the purpose of this volume "is to describe the various organic reagents (precipitants) used in gravimetric and volumetric analysis; to indicate the type of analysis in which they may be used; and to provide proved directions for their use." The use of organic reagents in colorimetric and spot-test analysis is not treated, as coverage of these subjects is adequate in monographs already published.

In the first four chapters is given a brief critical summary of the theory of the precipitation of metal cations by organic reagents, from both the chemical and physical viewpoints, including a discussion of the conditions necessary for quantitative separations. In subsequent chapters, necessary special techniques are described, and specific treatments are included of each of a dozen or more significant types of organic reagents, along with detailed directions for about 150 individual analyses.

The reviewer feels that this book will serve a useful function in helping to focus the attention of analytical chemists on a field too often overlooked, and to point the way for research endeavor along many lines of potential importance. It will also be a helpful handbook for the practical analyst who needs workable directions for specific analyses.

The few instances of errors and unclear passages are not such as to detract materially from the usefulness of the theoretical treatment and the accuracy of the analytical procedures. The index might be more complete.

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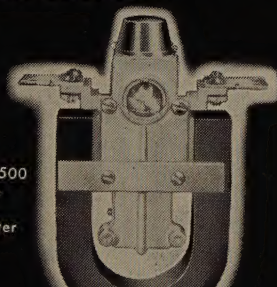

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### DESIGN OF MACHINE ELEMENTS

M. F. Spotts—Prentice-Hall, Inc., New York. 1948. 414 pp. $6.65.

Mr. Spotts has prepared a book which presents the fundamentals and up-to-date design data of machine elements.

The subject matter has been presented in a clear, concise, and convincing manner. The student is given a clear picture of the elements considered without becoming involved with excessive technical detail; yet the engineer will find the material treated in sufficient detail to assure him a clearer understanding of the fundamentals underlying them.

Mr. Spotts has courageously included a chapter on Dimensioning and Details. He has clearly presented the fundamental principles back of proper dimensioning of detail drawings, in order to properly convey all necessary information to the manufacturing organization to permit economic production.

The bibliography at the end of each chapter refers to many authors on the subject covered and thus suggests additional valuable material to the reader. There are also examples at the end of each chapter which, if solved, will help the student to retain more firmly the fundamentals pertaining to the element under consideration.

This is a book which engineers will find useful in their libraries.

FRANK C. LINN

### INDUSTRIAL ELECTRONICS REFERENCE BOOK

Electronics Engineers of the Westinghouse Electric Corp.—John Wiley & Sons, New York. 1948. 690 pp. $7.50.

Here is a very practical approach to a popular and interesting subject. It has been written by a group of practicing engineers well qualified to cover the subjects assigned to them. Any engineer seeking fundamental and authoritative information will find this book very useful. In addition to the information given in the regular text, each chapter is concluded with a detailed list of reference material.

Unlike many books with similar title, this one covers the electron theory briefly, in a direct and clear manner. All types of tubes are briefly but adequately described by giving the underlying principles involved. Sufficient design information is given to insure a practical working knowledge of these tubes, including the klystron, magnetron, and x-ray tubes.

Nine chapters are used to cover circuit elements and fundamental control circuits. These chapters treat many communication elements and circuits; most important fundamentals are covered and many industrial application examples are given.

A separate chapter is devoted to each c the main industrial applications, such a electronic motor control, resistance-weldin control, radio-frequency heating, photo electric applications, and electronic instru ments including x-ray equipment and th electron microscope. The general subject c regulation and stability is covered in on chapter, which small amount of material o such an important subject may be disap pointing to some readers; however a list c 20 references is given at the end of th chapter.

In addition to industrial application there are chapters on radar, carrier curren on power lines, ultraviolet application transmission lines, and antennas. A fe fundamental general considerations on th servicing of both tubes and equipmen appear at the end of the book.

HARRY L. PALME

### PRACTICAL JOB EVALUATION

Philip W. Jones—John Wiley & Sons, Inc New York. 1948. 320 pp. $4.00.

This book should be extremely informa tive to a student desiring knowledge of th history, principles, philosophy, method and application of Job Evaluation.

To the business or union executive, th explanation of the attendant procedure necessary to accomplish a satisfactor installation and administration of a Jo Evaluation program should serve as warning that any such program is not to b considered carelessly. For this reason alon the book makes valuable reading.

W. P. PARSON

### CONCISE CHEMICAL AND TECHNICAL DICTIONARY

Edited by H. Bennett—Chemical Publish ing Co., Inc., Brooklyn, N. Y. 1947. 105 pp. $10.00.

Here is a book that will be welcomed b the thousands who have found need to con sider, use, and talk about the elements tha make up the modern world of technology More and more this domain is pressing upo our daily lives; and its growing complexit constantly requires the learning of ne words that describe materials, processe and things. It is not strange, perhaps, tha some who were even schooled as enginee find it hard to survive in the rushing floo of new knowledge. This dictionary is th sort of book that constitutes a chart an compass in that modern sea of technic terms. It briefly defines a multitude of word abbreviations, and symbols that occur i commerce and industry; in specification advertisements, labels, or technical paper in periodicals and books; and frequently i daily conversations. Its definitions—bri as they are, and must be—serve admirabl to orient and guide the uninformed an sometimes bewildered searcher into th channels that lead to more adequa knowledge. Frequently, too, the specif data given—chemical formula, molecul weight, specific gravity, melting point, an such properties—suffice immediately.

The production of a dictionary of tec nical terms is an ambitious undertaking. becomes a formidable one when the fields chemistry, physics, and engineering a covered. This one, designed for both pr fessionals and laymen, contains about 50,000 definitions of chemical, physical, metallurgical, mineralogical, biological, medical, pharmaceutical, mathematical, and botanical terms.

In actual use the dictionary has proved remarkably informative, particularly with regard to breadth of coverage and variety of terms defined. A good balance has been struck between completeness and physical size; and the degree of adequacy that has been achieved makes the volume most useful for ready reference. The usefulness of its listing and identification of trade names is particularly gratifying; but the capitalization given in its spelling of these names should be observed with caution, because in some cases it does not agree with specific requirements. This, however, is a matter of specialization and does not interfere with the book's inherent usefulness and excellence.

J. E. Glick

### Meson Theory of Nuclear Forces (Second Edition)

Wolfgang Pauli—Interscience Publishers, Inc., New York. 1948. 69 pp. $2.00.

This informal monograph is based on a series of lectures delivered by Dr. Pauli at the Massachusetts Institute of Technology in the autumn of 1944. The second edition is not essentially different from the first, which appeared in 1946.

During the past two years the earlier ideas on meson theory have been greatly changed by the discovery of at least one new kind of meson, and by the observation that the negative mesons usually found in cosmic rays are not captured by light nuclei. In addition, physicists have made considerable progress in learning how to avoid divergence difficulties in meson-theory calculations. These newer developments have not been described in Pauli's book; indeed, any attempt to adequately cover them at the present time would be premature in view of the rapidly changing status of the theory.

Thus, Pauli's book has value not as an up-to-date and definite text on the subject, but rather as an indication of the type of problem that meson theory tries to solve, and an illustration of mathematical formalisms which will undoubtedly play some prominent role in the theory no matter what form it ultimately takes. For the student who is interested in acquiring a detailed familiarity with the mathematical techniques of meson theory, and who is not averse to studying material which is in part obsolete, the book is of considerable value.

H. Hurwitz, Jr.

### Glass: The Miracle Maker (Second Edition)

C. J. Phillips—Pitman Publishing Corp., New York. 1948. 448 pp. $6.00.

It has been a pleasure to review this book again. The new edition shows many signs of rewriting in certain parts, with eliminations and rather important additions, bringing the book up-to-date, mostly through 1946.

Part One, on History and Technology, shows little change in the historical part or in the fundamentals and chemistry of glass. The Periodic Table of the Elements looks bare without its list of rare earth elements, so important in the making of colored glasses. The inexcusable use of the term "glass-forming oxides" to cover all oxides used in glassmaking still persists. New material has been added in the sections on Mechanical Properties and on Other Physical Properties of glass, which include the contributions by Shand on the Electrical Properties. Here glasses and porcelains are compared.

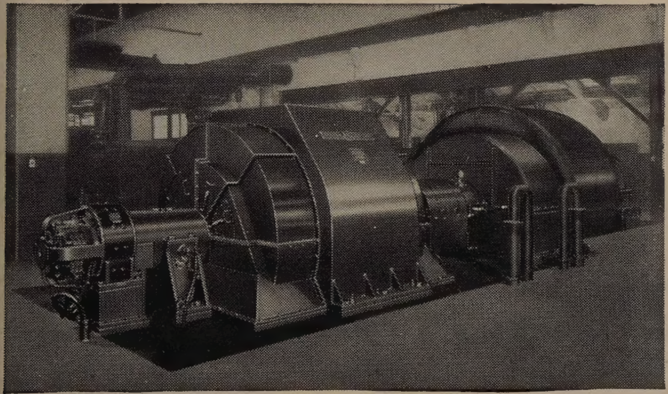
Part Two, on Manufacture, covers materials, furnaces, refractories, melting processes, and all manner of hand working and machine working of molten glass, from goblets and bottles to plate glass. There is new material on furnaces, glass-to-metal seals, practical stress limits for commercial annealing, and on the tolerances allowable in the making of some types of ware, particularly tubing.

Part Three, on Applications, shows many changes in the use of glass during the war period. The author's association with both the Corning Glass Works and the Pittsburgh Plate Glass Co. has enabled him to add more authoritative material to his book. Uses include glass for buildings and homes, for cooking and tableware, and for illumination. The technical applications include glasses for the electrical industry, for science and research, and in manufacture. Bent glass gets a page, and glass pin-type power insulators are removed. Metallizing glass is becoming an important technical art. High-voltage x-ray tubes and betatrons take their place with the silicones and organic plastics used to imbed glass fibers.

In so large a work new errors are bound to creep in—such as in the viscosities on page 98. The dielectric constant K of lead glass should be 8.2, not 2.2. The index should give the initials of W. R. Whitney and L. A. Hawkins and should not include the latter half of Schott und Genössen as an author!

The matt paper makes the reading easier but diffuses somewhat the 200 fine illustrations.

Louis Navias



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# LIBRARY NOTES

## ON ARTICLES IN OTHER TECHNICAL JOURNALS

### AIR CONDITIONING

Conditioning of Hot Humid Air, by Ralph E. Peck and Charles J. Ryant, Jr. *Refrig. Engng.*, Nov. 1948; v. 56, pp. 417-421.

The process studied removes heat and moisture from hot humid air with a hygroscopic salt solution and at the same time cools the solution.

How to Avoid Condensation Troubles When Using Cold Primary Air Ducts, by John Everetts, Jr. *Heat. Piping & Air Cond.*, Nov. 1948; v. 20, pp. 71-75.

Description of tests yielding data on insulation methods.

### BEAMS

Bending and Buckling of Sandwich Beams, by N. J. Hoff and S. E. Mautner. *Jour. Aero. Sci.*, Dec. 1948; v. 15, pp. 707-720.

Formulas are derived for the calculation of the deflections of sandwich beams and of the buckling load of sandwich columns. Beam and column tests carried out on 64 specimens are described.

### ELECTRIC CONDUCTORS

When You Consider Using Aluminum Wire and Cable, by G. A. Van Brunt. *Factory Man. & Maint.*, Nov. 1948; v. 106, pp. 126-128.

A comparison of the properties of aluminum and copper for electric conductors.

### ELECTRIC FURNACES

Split-type Electric Furnace for Galvanizing Baths, by Wallace G. Imhoff. *Iron Age*, Nov. 11, 1948; v. 162, pp. 114-115.

Describes sectional and ring-type furnaces, developed in Australia, which are especially designed to permit rapid and easy removal of the furnace from around the kettle.

### ELECTRIC HEATING

Elimination of Standing Waves on Electrodes for High-frequency Dielectric Heating, by E. R. Bell and M. E. Dunlap. *Tech. Data Digest*, Dec. 15, 1948; v. 13, pp. 13-21.

How standing waves on long electrodes can be avoided by multiple tuning of the electrodes with the use of relatively high frequencies, and by connecting the generator to the electrodes at two points when using low frequencies.

### ELECTRIC LIGHTING

Practical Mechanics of Designing Optimum Lighting Patterns, by H. L. Logan. *Illum. Engng.*, Dec. 1948; v. 43, pp. 1233-1269.

A study of illumination as influenced by the fact that seeing takes place in a three-dimensional space having many "folds."

### ELECTROMAGNETIC THEORY

Generalized Magneto-ionic Theory, by N. C. Gerson and S. L. Seaton. *Franklin Inst. Jour.*, Dec. 1948; v. 246, pp. 483-494.

A vector equation relating the polarization of a homogeneous isotropic medium to an external impressed magnetic field, derived under the condition that the medium is penetrated by an electromagnetic wave.

### ELECTROPLATING

Electroplating Methods Used in One of the World's Largest Installations. *Mach.*, Nov. 1948; v. 55, pp. 208-212.

Description of one of the largest and most completely automatic copper-nickel-chromium electroplating installations now in operation.

### FOUNDRY PRACTICE

Patterns and Molding Methods for Steel Castings, by John Howe Hall. *Foundry*, Nov. 1948; v. 76, pp. 80-83, 212, etc.

The first of five articles describing available types of patterns, their proper selection, and the molding methods to which each is best adapted.

### GAS FLOW

Flow of a Compressible Fluid Through a Series of Identical Orifices, by C. S. L. Robinson. *Jour. App. Mech.*, Dec. 1948; v. 15, pp. 308-310.

A method for computing the weight flow of a gas or vapor through a number of like orifices. It is based upon the general equation for a single orifice and upon certain reasonable assumptions.

### INSULATION

Liquid Dielectrics for Transformers, by J. G. Ford. *Elec. Engng.*, Nov. 1948; v. 67, pp. 1066-1071.

Considers the fireproof askarels as well as the combustible hydrocarbons.

Factors Affecting the Cost of Purifying Insulating Oil, by H. V. Niles. *Elec. Wld.*, Nov. 6, 1948; v. 130, pp. 92-94.

Examines factors tending to cause excessive conditioning costs; suggests procedures that can effect more economy.

Electrical Insulation; Navy's Program Moves Ahead, by Alex. E. Javitz. *Elec. Mfg.*, Nov. 1948; v. 42, pp. 88-93, 188, etc.

The development of improved fire- and arc-resistant plastics laminates and molded materials for lighter, more compact, and more reliable shipboard electrical apparatus.

### LABORATORIES

Modern Research Facilities of Federal Telecommunication Laboratories, by H. H. Buttner. *Elec. Commun.*, Sept. 1948; v. 25, pp. 211-219.

Includes a description of a 300-foot aluminum-sheathed microwave research tower.

### LUBRICATION AND LUBRICANTS

Antifriction Bearing Developments, by A. Stewart Murray. *Lubrication Engng.*, Dec. 1948; v. 4, pp. 252-256, 274.

On the mist lubrication of such bearings.

The Development of a New Grease. *Lubrication*, Dec. 1948; v. 34, pp. 133-144.

How lubricating greases are made.

Guide for Plant Operator in Preparing New Turbine Oil System. *Power*, Nov. 1948; v. 92, pp. 691-693.

An ASTM committee recommends a procedure for preparing the lube system of a direct-connected turbine for its first oil charge.

### MACHINERY

A Little Heat Eases Press-fit Rotors On Their Shafts, by N. L. Rea. *Power*, Nov. 1948; v. 92, pp. 682-684.

Use of a relatively small temperature increase to expand a large-rotor bore more than its press-fit tolerance.

Economy by Efficient Calculation, by W. Heigh. *Inst. Engrs. & Shipbldrs. Trans.*, Nov. 1948; v. 92, pp. 31-64.

Presents a method for simplifying the design and layout of steel-plate structures, particularly ships. Numerous folded charts showing design data are included.

Precise Processing Produces Flatirons Faster, by Leo J. Pantas. *Am. Mach.*, Nov. 4, 1948; v. 92, pp. 98-100.

How die-cast aluminum shoes with cast-in heating elements, combined with ingenious tooling, speed production of domestic flatirons.

### MEASURING INSTRUMENTS

Making Special Measurements, by H. Johnston. *Power Gen.*, Nov. 1948; v. 52, pp. 74-77.

Describes instruments and methods used in measuring several unusual quantities associated with production processes.

The Derivative Controller, by V. V. St.L. Tivy. *Instruments*, Dec. 1948; v. 21, pp. 1096-1099, 1130.

The controller's purpose is to detect and correct for changes in the process being regulated.

### METALS

Powdered-metal Friction Material, by Francis J. Lowey. *Mech. Engng.*, Nov. 1948; v. 70, pp. 869-875.

On the fabrication, properties, and applications of sintered powdered-metal facings for friction brakes, clutches, etc.

Shot Peening, by F. P. Zimmerli and John Straub. *Soc. Auto. Engrs. Jour.*, Nov. 1948; v. 56, pp. 36-39.

Deals with the effect of shot type on spring fatigue life, and the importance of uniform shot.

### NUCLEAR PHYSICS

Nuclear Physics and Low Temperatures, by M. E. Rose. *Nucleonics*, Dec. 1948; v. 3, pp. 23-31.

Describes some recent developments in nuclear physics and low temperatures, certain related problems of common interest, and the adoption of new techniques.

### PRECISION INVESTMENT CASTING

Polystyrene in Centrifugal Casting. *Modern Plastics*, Nov. 1948; v. 26, pp. 112-115.

Advantages offered by plastic material over wax in producing metal castings by the "lost-wax" process.

### SILICONES

Vinyl and Allyl Silicone Polymers and Copolymers, by D. T. Hurd and G. F. Roedel. *Ind. & Engng. Chem.*, Nov. 1948; v. 40, pp. 2078-2081.

Deals with the properties of silicone resins.